Technical Memorandum No. 1

Subject:	Draft General Process and Distribution System Overview
Prepared For:	North Bay Watershed Association – Integrated Water Resources Committee
Prepared By:	Raines, Melton & Carella, Inc.
Date:	May 18, 2004
Task No. :	**041-07-02 and 05**

Contents

Table of Figures:

Table of Tables:

Section 1 Introduction

The North Bay Watershed Association's (NBWA's) Integrated Water Resources Committee is conducting a study to understand the feasibility of locating a Satellite Water Recycling Facility within the water service areas of Marin Municipal Water District, North Marin Water District, the Sonoma Valley County Sanitation District, and the City of Napa. This work grows out of the North Bay Regional Water Recycling Study (the Regional Study) but has a different perspective. The Regional Study asked the question, "If the North Bay agencies were to act together on a regional recycling project, would it be possible to go to zero discharge?" This study asks the question, "If we look closely at our neighborhoods, can we generate a viable water supply from what would otherwise be wastewater?" The Regional Study has a discharge elimination focus and this study has a water supply focus.

All water recycling projects require cooperation between the water supply agency and the agency responsible for wastewater treatment. In this case, the water service areas described above include the service area of the following agencies responsible for wastewater treatment:

- Marin County Sanitary District #5
- Sausalito-Marin City Sanitary District
- Sewerage Agency of Southern Marin
- Richardson Bay Sanitary District
- Central Marin Sanitation Agency
- Las Gallinas Valley Sanitary District
- Novato Sanitary District
- Sonoma Valley County Sanitation District
- Napa Sanitation District

Figure 1 Study Area

Figure 1 illustrates the study area, the approximate limits of each water supply agency's service area and the location of the central wastewater treatment facilities.

1.1 Purpose

The overarching purpose of the Satellite Treatment Study is to identify feasible locations for remote water recycling facilities, in which "remote" means located away from the centralized wastewater treatment plant. This first Technical Memorandum is focused on outlining the general considerations that go into siting a satellite water recycling facility and developing some basic cost estimating tools that can be used in evaluating candidate locations. Subsequent Technical Memoranda will apply these general criteria in each specific water service area in order to analyze the feasibility of a satellite plant.

Figure 2 illustrates the decision process that guides this study. It is based on comparing the cost of recycled water to the cost of providing potable water for the same purpose. The remainder of this Technical Memorandum discusses the steps illustrated in this decision process and is intended to provide a general overview of the screening process used to identify candidate satellite water recycling projects.

However, other factors should also be considered by agencies in evaluating the feasibility of recycled water projects. For example, recycled water projects can provide wastewater related benefits by reducing the mass of wastewater discharged to the receiving water, environmental benefits by postponing development of new potable water sources, public education benefits by illustrating the value of water, etc. The value of these other benefits will vary widely depending on the driving forces behind implementation of a particular recycled water project. The economic evaluations is this Technical Memorandum should be supplemented by these site-specific factors, if possible by monetizing the benefits and including them in the benefit/cost comparison. If the benefits can not be translated into monetary values, a supplemental decision process that incorporates economic and non-economic factors can be used.

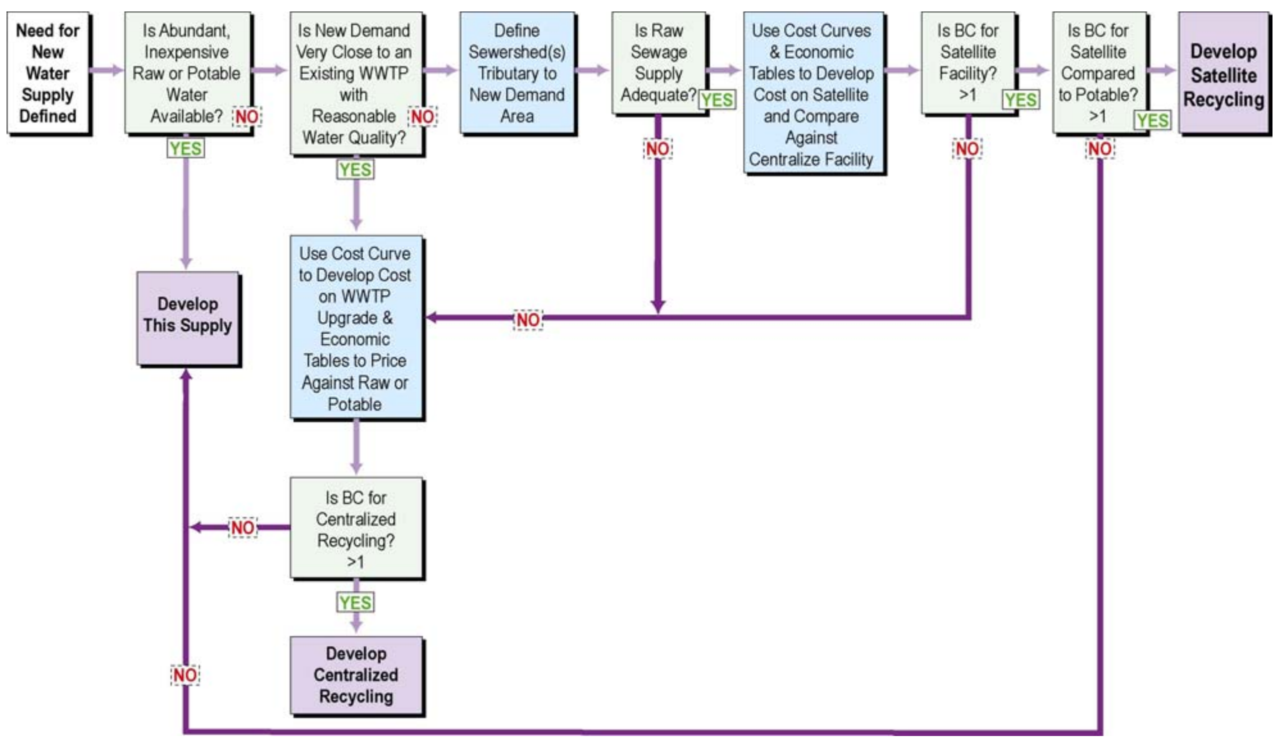


Figure 2 Decision Process Flow Chart Based on Comparative Costs of Water Supplies

1.2 Definitions and Assumptions

This study is focused on a specific type of facility intended to satisfy a water demand in a relatively remote location. This study limits both the flow range and technology options reviewed in order to focus on systems that do not require custom process design, can be delivered to remote sites affordably and which lend themselves to a general evaluation technique that can be used by many different agencies as a first-order screening tool. In addition, because this study is prepared for northern California agencies, the study assumes that all beneficial reuse will be governed by the standards outlined in California's Code of Regulations, Title 22 (Title 22). Title 22 proscribes very high standards for recycled water quality effluent, which may not be universally required.

Two definitions are offered below which will be utilized to limit the range of analysis considered in this study.

> ***Satellite Water Recycling Facility***: a satellite water recycling facility is defined as a package treatment plant that allows an agency to produce high quality effluent for beneficial reuse. Satellite facilities are relatively small (typically less than 1 mgd) compared to a centralized treatment facility and will generally be located adjacent to a trunk sewer, allowing raw wastewater to be diverted to feed the plant and allowing solids generated from the treatment process to be discharged directly back to the trunk sewer. Satellite facilities can be operated as small "water factories", which generate recycled water when there is adequate demand and that can be by-passed when there is no need for the additional water supply. This type of facility is also occasionally referred to a "scalping plant". Figure 3 provides a conceptual illustration of a satellite water recycling facility.

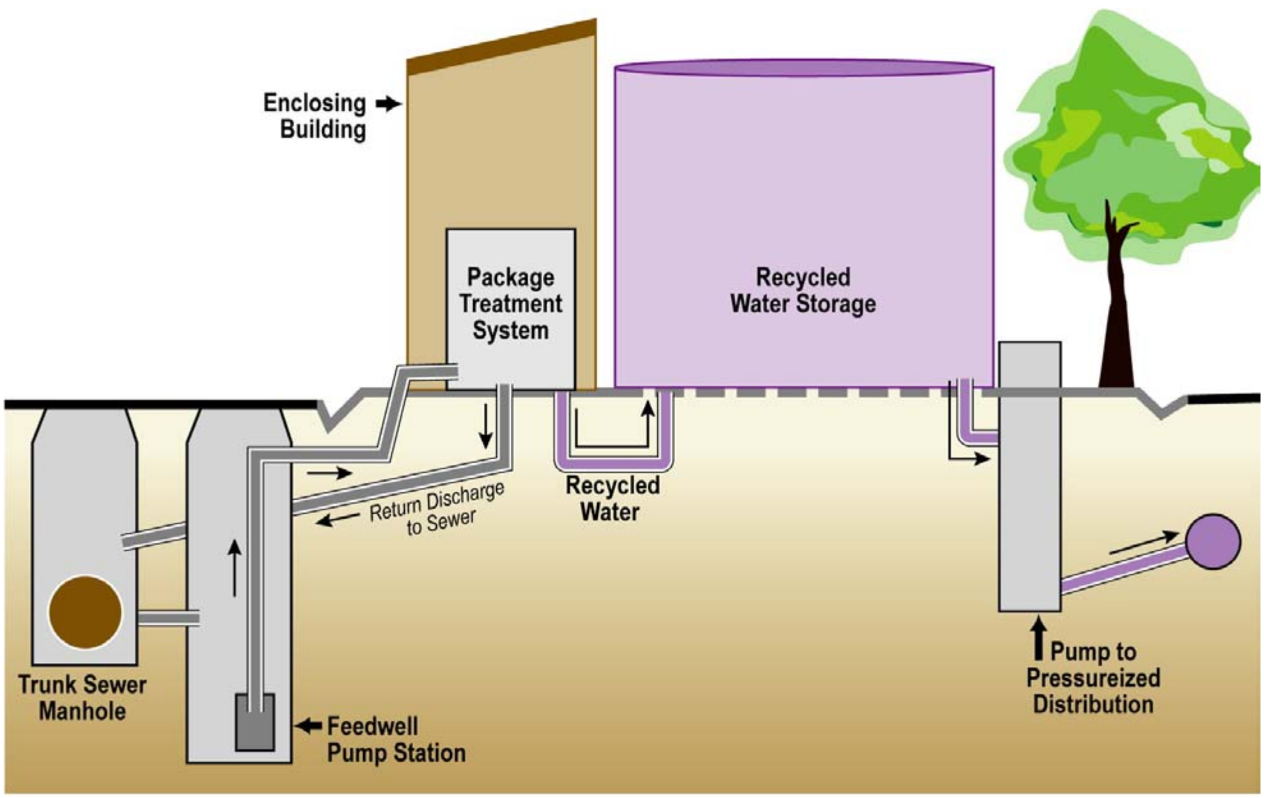


Figure 3 Satellite Plant Conceptual Illustration

> ***Package Treatment Plant:*** a package treatment plant is a wastewater treatment plant capable of producing effluent that meets at least secondary quality, in which each process component is designed and produced by a single manufacturer and which is generally available for delivery to the site as a complete unit. For those package plants producing secondary quality effluent, additional tertiary filtration and disinfection are required to meet Title 22 requirements.

1.3 When to Consider a Satellite Water Recycling Facility

Satellite water recycling facilities bear consideration under several different sets of circumstances.

1. A significant single water user or a concentration of water users is located at some distance from a central wastewater treatment or water recycling facility. In this case the cost of the package treatment plant and local recycled water distribution system may be less than the cost of adding tertiary treatment facilities and extending the distribution system from the central wastewater treatment plant.
2. Influent quality to the central wastewater treatment plant or water recycling facility is poor, typically from high total dissolved solids, or salty due to salt water intrusion or industrial discharges into the sewer collection system. In this case the cost of a package treatment plant, located upstream outside of the salt water intrusion or industrial discharge area, may be less than the cost of the advanced treatment technology, such as reserve osmosis needed to remove salts and produce water suitable for reuse.

1.4 Alternatives for Comparison

Although this Technical Memorandum focuses on recycled water as a water supply, recycled water can also provide benefits to a wastewater agency by reducing the mass loading of wastewater discharged. If, for example, a wastewater agency is required to reduce its mass loading of discharge, it could proceed in two directions:

- Develop a recycled water to divert flow, and therefore mass, from the discharge
- Upgrade the treatment processes to increase the removal efficiency through the plant.

Often, development of a recycled water project is a more cost-effective alternative and provides ancillary water supply and environmental benefits. The benefits of reduced wastewater discharge tend to be site-specific depending on whether this is an issue of concern for the wastewater agency. Therefore, in addition to the water supply benefits discussed in this memorandum, evaluation of recycled water projects should also determine whether there are specific wastewater-related benefits that should be incorporated in the economic evaluation.

As related to water supply benefits, a satellite treatment plant's feasibility as a water supply can be determined by comparing its cost-effectiveness to two basic alternatives. The first alternative water supply strategy is expansion of the existing water system to serve the need. This can generally be modeled as the cost of the next "new" increment of water supply that an agency needs to purchase. The next "new" increment could be conserved water and this comparison should be made if possible. The second alternative water supply strategy is development or expansion of a centralized water recycling facility. Figure 4 illustrates how in a single water service area, some customers might be most affordably served with recycled water processed at a central plant, some by recycled water processed at a satellite plant and some customers might be most affordably served by potable water.

Figure 4 Example of Economically Viable Supply Strategies

Section 2 Types of Demand

Since a satellite water recycling facility acts as a water factory, determining the location and water quality requirements of the customer is primary to the analysis. The decision to begin a feasibility analysis for a satellite water recycling facility is essentially the identification of the water demand that needs to be met. Solutions for meeting this demand could include providing potable water, if available, or providing recycled water from either a centralized wastewater plant or from a satellite recycled water facility. This section outlines the regulatory requirements that need to be satisfied for various classes of recycled water users and additional requirements that may be specific to certain types of customers. This section goes on to present several techniques for determining potential recycled water customers within a water service area and accounting for their demand patterns.

2.1 Regulatory Treatment Standards for Various Types of Water Users

In California, water recycling criteria is outlined in Title 22 of the California Code of Regulations beginning with Section 60301 (the "State Water Recycling Criteria"). The State Water Recycling Criteria outlines several types of recycled water including:

- Disinfected Tertiary Recycled Water-the highest regulated water quality which includes a filtration step to achieve a turbidity of less than 2 Nephelometric Turbidity Units (a measure of the clarity of water, commonly abbreviated as ntu) in addition to disinfection to achieve a final median concentration of total coliform bacteria of less than 2.2 per 100 milliliters.

- Disinfected Secondary-2.2 Recycled Water-an unfiltered water quality that is disinfected to the same bacteriological standard as Disinfected Tertiary.
- Disinfected Secondary-23 Recycled Water- an unfiltered water quality that is disinfected to achieve a final median concentration of total coliform bacteria of 23 per 100 milliliters.
- Undisinfected Secondary Recycled Water-an unfiltered, undisinfected water quality that is produced through a secondary wastewater treatment process. [1]

Table 1 outlines the approved end uses for each type of recycled water. This Technical Memorandum assumes that most water agencies will be looking to satisfy demands that require Disinfected Tertiary Recycled Water.

Table 1 Regulatory Standards for Water Quality

	Treatment Levels			
Irrigation	**Disinfected Tertiary Recycled Water**	**Disinfected Secondary-2.2 Recycled Water**	**Disinfected Secondary-23 Recycled Water**	**Undisinfected Secondary Recycled Water**
Food crops where recycled water contacts the edible portion of the crop, including all root crops	**Allowed**	Not allowed	Not allowed	Not allowed
Parks and playgrounds	**Allowed**	Not allowed	Not allowed	Not allowed
School yards	**Allowed**	Not allowed	Not allowed	Not allowed
Residential landscaping	**Allowed**	Not allowed	Not allowed	Not allowed
Unrestricted access golf courses	**Allowed**	Not allowed	Not allowed	Not allowed
Any other irrigation uses not prohibited by other provisions of the California Code of Regulations	**Allowed**	Not allowed	Not allowed	Not allowed
Food crops where edible portion is produced above ground and not contacted by recycled water	**Allowed**	**Allowed**	Not allowed	Not allowed
Cemeteries	**Allowed**	**Allowed**	**Allowed**	Not allowed
Freeway landscaping	**Allowed**	**Allowed**	**Allowed**	Not allowed
Restricted access golf courses	**Allowed**	**Allowed**	**Allowed**	Not allowed
Ornamental nursery stock and sod farms	**Allowed**	**Allowed**	**Allowed**	Not allowed
Pasture for milk animals	**Allowed**	**Allowed**	**Allowed**	Not allowed
Nonedible vegetation with access control to prevent use	**Allowed**	**Allowed**	**Allowed**	Not allowed

[1] California Code of Regulations, Title 22, Section 60301 et. seq., "Definitions"

Irrigation	Treatment Levels Disinfected Tertiary Recycled Water	Disinfected Secondary-2.2 Recycled Water	Disinfected Secondary-23 Recycled Water	Undisinfected Secondary Recycled Water
as a park, playground or school yard				
Orchards with no contact between edible portion and recycled water	**Allowed**	**Allowed**	**Allowed**	**Allowed**
Vineyards with no contact between edible portion and recycled water	**Allowed**	**Allowed**	**Allowed**	**Allowed**
Non food-bearing trees, including Christmas trees not irrigated less than 14 days before harvest	**Allowed**	**Allowed**	**Allowed**	**Allowed**
Fodder crops (e.g. alfalfa) and fiber crops (e.g. cotton)	**Allowed**	**Allowed**	**Allowed**	**Allowed**
Seed crops not eaten by humans	**Allowed**	**Allowed**	**Allowed**	**Allowed**
Food crops that undergo commercial pathogen-destroying processing before consumption by humans	**Allowed**	**Allowed**	**Allowed**	**Allowed**
Ornamental nursery stock, sod farms not irrigated less than 14 days before harvest	**Allowed**	**Allowed**	**Allowed**	**Allowed**

Supply for Impoundment	Treatment Levels Disinfected Tertiary Recycled Water	Disinfected Secondary-2.2 Recycled Water	Disinfected Secondary-23 Recycled Water	Undisinfected Secondary Recycled Water
Non-restricted recreational impoundments, with supplemental monitoring for pathogenic organisms	**Allowed** [2]	Not allowed	Not allowed	Not allowed
Restricted recreational impoundments and publicly accessible fish hatcheries	**Allowed**	**Allowed**	Not allowed	Not allowed
Landscape impoundments without decorative fountains	**Allowed**	**Allowed**	**Allowed**	Not allowed

	Treatment Levels			
Supply for Cooling or Air Conditioning	**Disinfected Tertiary Recycled Water**	**Disinfected Secondary-2.2 Recycled Water**	**Disinfected Secondary-23 Recycled Water**	**Undisinfected Secondary Recycled Water**
Industrial or commercial cooling or air conditioning involving cooling tower, evaporative condenser, or spraying that creates a mist	**Allowed 3**	Not allowed	Not allowed	Not allowed
Industrial or commercial cooling or air conditioning not involving a cooling tower, evaporative condenser, or spraying that creates a mist	**Allowed**	**Allowed**	**Allowed**	Not allowed

	Treatment Levels			
Other Uses	**Disinfected Tertiary Recycled Water**	**Disinfected Secondary-2.2 Recycled Water**	**Disinfected Secondary-23 Recycled Water**	**Undisinfected Secondary Recycled Water**
Groundwater recharge	**Allowed under special case-by-case permits by RWQCBs [4]**			
Flushing toilets and urinals	**Allowed**	Not allowed	Not allowed	Not allowed
Priming drain traps	**Allowed**	Not allowed	Not allowed	Not allowed
Industrial process water that may contact workers	**Allowed**	Not allowed	Not allowed	Not allowed
Structural fire fighting	**Allowed**	Not allowed	Not allowed	Not allowed
Decorative fountains	**Allowed**	Not allowed	Not allowed	Not allowed
Commercial laundries	**Allowed**	Not allowed	Not allowed	Not allowed
Consolidation of backfill material around potable water pipelines	**Allowed**	Not allowed	Not allowed	Not allowed
Artificial snow making for commercial outdoor uses	**Allowed**	Not allowed	Not allowed	Not allowed
Commercial car washes not done by hand & excluding the general public from washing process	**Allowed**	Not allowed	Not allowed	Not allowed
Industrial boiler feed	**Allowed**	**Allowed**	**Allowed**	Not allowed
Nonstructural fire fighting	**Allowed**	**Allowed**	**Allowed**	Not allowed
Backfill consolidation around nonpotable piping	**Allowed**	**Allowed**	**Allowed**	Not allowed
Soil compaction	**Allowed**	**Allowed**	**Allowed**	Not allowed

	Treatment Levels			
Other Uses	**Disinfected Tertiary Recycled Water**	**Disinfected Secondary-2.2 Recycled Water**	**Disinfected Secondary-23 Recycled Water**	**Undisinfected Secondary Recycled Water**
Mixing concrete	**Allowed**	**Allowed**	**Allowed**	Not allowed
Dust control on roads and streets	**Allowed**	**Allowed**	**Allowed**	Not allowed
Cleaning roads, sidewalks and outdoor work areas	**Allowed**	**Allowed**	**Allowed**	Not allowed
Flushing sanitary sewers	**Allowed**	**Allowed**	**Allowed**	**Allowed**

[1] Refer to the full text of the latest version of Title-22: California Water Recycling Criteria. This chart is only a guide to the September 1998 version.
[2] With "conventional tertiary treatment." Additional monitoring for two years or more is necessary with direct filtration.
[3] Drift Eliminators and/or biocides are required if public or employees can be exposed to mist.
[4] Refer to Groundwater Recharge Guidelines, California Department of Health Services.

2.2 Additional Customer Requirements for Treatment

In addition to the basic regulatory requirements for water quality, water users may have specific water quality requirements. Customers that utilize water for agricultural or horticultural purposes can be particularly sensitive to the salt content of the water supply (indeed a satellite recycling facility may prove practical if it can capture wastewater prior to saltwater contamination). Certain types of industrial process use are also sensitive to salts and total dissolved solids (TDS) in process water. Often times these types of users will employ additional point-of-use treatment devices to meet their water quality requirements, even if the water source is the potable supply. In every case it is important for the agency considering a recycled water project to understand its customers' water quality requirements and willingness to provide point-of-use treatment prior to beginning the initial feasibility and screening process.

2.3 Identifying Water Users

There are two basic techniques for identifying water users that could potentially be serviced by or converted to a recycled water supply, were it available. The first, and preferred method, is to use the historical water use records available to the local water purveyor. The second is to use land use mapping and generally accepted water demand factors. The second method is appropriate if metered use records are not available (i.e. for new water users or for users that have historically supplied their needs from unmetered groundwater).

2.3.1 Historical Water Use Method

This method utilizes the historical billing records of the water agency to identify large water users that could serve as "anchor tenants" for a satellite water recycling system. If an agency also has access to a GIS system, that tool can be utilized to plot the large water users graphically making clusters even easier to identify. Marin Municipal Water District has successfully used this method in its recently produced "Review of Water Recycling and Graywater"[2] . Figure 5 illustrates the graphic nature of this tool.

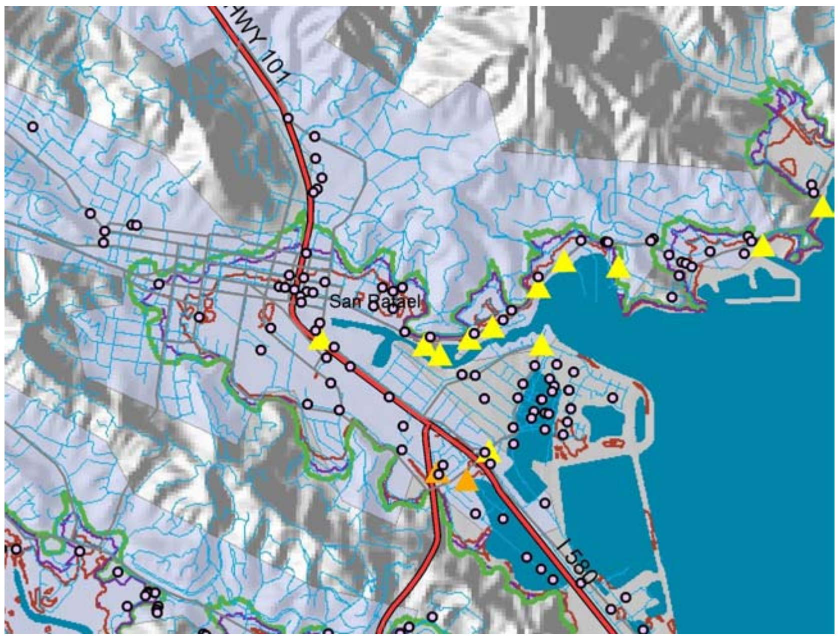


Figure 5 GIS Analysis Example

2.3.2 Land Use Method

This method is generally utilized when historical billing records aren't available. It is most commonly used when bringing customers onto the recycled water system, when they had previously used wells or if the "customer" is a new development project that has never been on the system before. This method basically applies a standard water consumption factor to known land uses in order to calculate an approximate demand. The North Bay Watershed Association has employed this method in its "Regional Water Recycling Study"[3]. Table 2 below illustrates the water consumption factors applied for various categories of land use. Note that is preferable to use local information whenever possible since local water usage can vary widely. For example, irrigation rates for golf courses in the North Bay range from 8.5 to 17 AF/year/hole, depending on the type of landscaping and the irrigation management practices.

---

[2] Marin Municipal Water District, "Review of Water Recycling & Graywater", Bahman Sheikh Ph.D., P.E. with Parsons Engineering Science.

[3] North Bay Watershed Association "North Bay Regional Water Recycling Feasibility Study", RMC, 2002.

Table 2 Land Use Based Demand Factors

Land Use	Demand Rate (AF/acre/year)
Vineyards	0.5
Irrigated Agriculture	2.0
Irrigated Pasture	2.5
Golf Courses	3.5
Urban Irrigation	3.0
Commercial/Industrial Process	1.7
Toilet Flushing	1.5 gal/flush

2.4 User Demand Patterns

Different classes of water users will place demand on the system at different times during the day. For example, industrial processing uses will often place demand during business hours as will commercial cooling and indoor plumbing uses (toilet flushing, institutional laundries etc.). Large irrigation users, however, will often place their full demand during a 6 to 8 hour night-time irrigation cycle. User patterns will also vary seasonally, with cooling and irrigation demand being reduced or even eliminated during the winter months. Implicit to this analysis is the assumption that the satellite treatment plant can be "turned-off" for the winter, when the irrigation demand is nonexistent. The cost curves in Section 7 are developed assuming the construction of process technology that lends itself to this mode of operation, which can be more expensive than technology that is designed to run year round.

As with water quality requirements, water demand patterns need to be generally understood prior to beginning the initial screening process. Figure 3 illustrates a conceptual satellite recycling facility including some onsite recycled water storage, under the assumption that the users' preferred demand pattern may not precisely match the plant's production rate. The cost curves, developed in Section 7, include an allowance for storage equal to 80% of average daily demand. The Cost Estimating Templates, included in the Appendix of this Technical Memorandum can be used modify this allowance and adjust the standard cost curve for a local agency's unique situation.

Section 3 Influent Flow Considerations

3.1 Locating Appropriate "Sewersheds"

A satellite water recycling facility can be reasonably considered when there is enough wastewater generated in the vicinity to actually meet the water demand needs on an average daily basis. Once water demands have been identified, the local agency will need to compare these to wastewater flows from tributary sewersheds. Determining wastewater flows in the sewershed can be done through historical flow records maintained by the local wastewater collection or treatment agency providing service in the area. Collection system flow records are often not available for individual sewersheds. Lacking that information, wastewater flow can be estimated by using land use mapping and applying design criteria for wastewater flow. However, if a satellite facility is determined to be feasible and metered flow data isn't available, the implementing local agency may wish to conduct wastewater flow monitoring as part of predesign to verify the actual wastewater flow available.

3.1.1 Historical Flow Method

This method utilizes flow monitoring data that is available to the wastewater agency. There are several common sources of this data that may be available to a local sewer agency. The first source of the data is a Sanitary Sewer System Evaluation (SSES) or Flow Monitoring Report. This type of reporting typically includes data from recording meters placed in manholes and can provide very reliable information on wastewater flows. A wastewater agency may have undertaken this work either as part of developing a system master plan or as a result of a regulatory requirement to manage its collection system.

If flow monitoring data is not available, but the tributary sewershed drains to a lift station, metered data may be available directly from the lift station or it may be possible to approximate the flow rates by understanding the lift station capacity and its operational pattern (i.e. Elapsed time meters show how often the lift stations run. This run time can be multiplied by the station capacity in order to approximate an average daily flow). As with large water users, sewershed capacity can be plotted from a GIS system, providing graphic illustration of the match between supply and demand.

3.1.2 Land Use Method

This method would be used when historical flow records aren't available. The method basically applies a standard waste water flow rate to known land uses in order to calculate approximate daily flows. Again, the local wastewater agency may have developed this work as part of its Master Planning efforts and local design criteria should always be used when possible. Table 3, on the following page, summarizes flow rates published by the State Water Resources Control Board, which can serve as "standard" data if local information is unavailable.

Table 3 Standard Wastewater Flow Rates for Various Establishments

Estimated Water Consumption at Different Types of Establishments			
TYPE OF ESTABLISHMENT	**Flow in gpd per person or unit (1)**	**TYPE OF ESTABLISHMENT**	**Flow in gpd per person or unit (1)**
Dwelling units, residential		Institutions	
Private dwellings on individual wells or metered supply	50-75	Average type	75-125
Private dwellings on public water supply, unmetered	100-200	Hospitals	150-250
Dwelling units, mulitple		Schools	
Apartment houses on individual wells	75-100	Day	5-10
Apartment houses on public water supply, unmetered	100-200	Day, with cafeteria or lunchroom	10-15
Hotels	50-100	Day, with cafeteria and showers	15-20
Boarding houses	50	Boarding	75
Lodging houses and tourist homes	40	Theaters	
Motels, without kitchens, per unit	100-150	Indoor, per seat, two showings per day	3
Camps		Outdoor, including food stand, per car	3-5
Pioneer type	25	Automobile service station	
Children's, central toilet and bath	40-50	Per vehicle served	10
Day camp, no meals	15	Per set of pumps	500
Luxury, private bath	75-100	Stores	
Labor	35-50	First 25 feet of frontage	450
Trailer with private toilet and bath, per unit	125-150*	Each additional 25 feet of frontage	400
Restaurants (including toilet)		Country clubs	
Average	7-10	Resident type	100
Kitchen wastes only	2.5-3	Transient type, serving meals	17-23
Short order	4	Offices	10-15
Short order, paper service	1-2	Factories, sanitary wastes, per shift	15-35
Bars and cocktail lounges	2	Self-service laundry	250-500
Average type, per seat	35	Bowling alleys, per alley	200
Average type, 24 hour, per seat	50	Swimming pools and beaches, toilet and shower	10-15
Tavern, per seat	20	Picnic parks, with flush toilets	5-10
Service area, per counter seat (highway)	350	Fairgrounds (based on daily attendance)	1
Service area, per table seat (highway)	150	Assembly halls, per seat	2
		Airport, per passenger	2

(1) Figures are flows per capita per day unless otherwise stated.
Source: Water Recycling Funding Guidelines, April 1997, California State Water Resources Control Board Office of Water Recycling

3.2 Wastewater Flow Patterns

As with water use, wastewater flow patterns vary over the course of any given day, meaning that the influent (or source water) for the satellite treatment plant will ebb and flow each day. In a large sewershed, this pattern may be dampened by storage provided in the sewer collection system. In a small sewershed, with uniform land use, the influent flow rate can show dramatic peaks. In general, the treatment processes described in Section 5 have sufficient hydraulic retention time so that diurnal peaking of the wastewater stream will not present an operational problem. However, the satellite facility, because of its small size and dependence on the local wastewater stream, will not provide as much hydraulic buffer as a centralized water recycling facility that can draw on the capacity of a larger treatment plant. The diurnal peaking of the wastewater stream should be considered when sizing any recycled water storage to make sure that decreases in influent flow rate do not create operational problems for the wastewater treatment process selected or the recycled water supply system.

3.3 Wastewater Quality Considerations

Because raw wastewater provides the “raw source” for a satellite treatment plant facility, it is important to make sure that this source water can meet a customer’s water quality needs. While the satellite plant facility will produce water that meets the requirements of State Water Recycling Criteria, the facility typically is not intended to remove unregulated constituents that can be of concern to customers. Irrigation and cooling demands are two of the large and more common water demands that may anchor a satellite recycling facility. General considerations for each type of use are outlined below. As noted above, some users will employ additional point-of-use treatment devices to meet their water quality requirements and in every case it is important for the agency considering a recycled water project to understand its customers’ water quality requirements and willingness to provide point-of-use treatment prior to beginning the initial feasibility and screening process.

3.3.1 General Considerations for Irrigation Customers

Irrigation management for turf, ornamental and agronomic crops is a science unto itself. At times a sound water management strategy can offset some of the effects of poor water quality. However, there are general standards for water quality with respect to irrigation use. These standards are reproduced as Table 4. Before embarking on an irrigation based recycling program, an agency should understand how its influent water quality matches these general standards in order to avoid too much investment in a poor quality source.

Table 4 Water Quality Standards for Irrigation Use

Quality Factor	Threshold Concentration (1)	Limiting Concentration (2)
Total Dissolved Solids, mg/l	500 (5)	1500 (5)
Electrical Conductivity mmhos/cm	750 (5)	2250 (5)
Range of pH	7.0-8.5	6.0-9.0
Sodium Adsorption Ratio (3)	6.0 (5)	15
Residual Sodium Carbonate meq (4)	1.25 (5)	2.5
Arsenic, mg/l	1.0	5
Boron, mg/l	0.5	2
Chloride, mg/l	100 (5)	250
Sulfate, mg/l	200 (5)	100
Copper, mg/l	0.1 (5)	1

(1) Threshold values at which irrigator might become concerned about water quality and might consider using additional water for leaching. Should be satisfactory for most species in arable soil.

(2) Limiting value at which landscape or crop quality will be drastically affected by water quality.

(3) Sodium adsorption ratio is defined by the formula $SAR = Na/(CA+Mg)^{1/2}$ where the concentrations are expressed in milli-equivalents per liter.

(4) Residual sodium carbonate is the sum of the equivalents of normal carbonate and bicarbonate minus the sum of the equivalents of calcium and magnesium.

(5) Values not to be exceeded more than 20% of the time.

Source: Todd. D.K. (1970) Water Encyclopedia (Port Washington NY, Water Information Center)

3.3.2 General Considerations for Cooling Towers

Use of recycled water for cooling tower purposes requires consideration for three general water quality parameters. Ammonia and phosphorus concentrations in recycled water can have a detrimental affect on the materials of construction of some cooling towers. Understanding the users' specific site is important for this reason. Ammonia and phosphorus are essentially nutrients found in wastewater, and some treatment processes can be managed for nutrient removal if this is important to the end uses. Cooling tower use is also sensitive to the Total Dissolved Solids (TDS) in the recycled water. The higher the TDS concentrations in the water, the fewer the cooling cycles that can be accomplished. This has the effect of increasing water demand from the cooling use and can also increase the energy demand associated with the overall system, as more pumping is required.

Section 4 Siting Considerations and Assumptions

While initial identification of candidate users for satellite-treated recycled water is based on water demand and location relative to a sewer trunk, several other factors should be considered when choosing the physical site for the satellite treatment plant. These factors can vary widely between sites and need to be analyzed on a case-by-case basis. These considerations include:

- Land Area Available
- Utility Systems in Area
- Storage Needs
- Backup Water Supply Needs
- Solids Disposal
- Community Acceptability

All of the above considerations have significant cost impacts and may determine which treatment technologies are most favorable for recycled water production. Because of this, it is important to consider each of these factors early in the decision-making process for satellite treatment feasibility.

4.1 Land Area Available

The first priority for finding a candidate site is to find a site that is large enough to accommodate the satellite plant. As discussed in Section 5, package plants can significantly vary in footprint size. Size of plant (and therefore land area required) depends on the treatment process chosen as well as the volume of wastewater treated.

Site selection must review, in part,

- Adequacy of existing or planned support and service facilities including utilities, roads, and parking areas
- Architectural and functional compatibility with the surrounding environment
- Interrelationships between facilities and aesthetic compatibility
- Noise control
- Odor control
- Natural topographic conditions
- Existing cultural and archeological resources

The cost analysis developed in Section 7 assumes that the package treatment plant unit is a Membrane Bioreactor. This package technology accomplishes secondary treatment and filtration in a single tank, with a minimal footprint. The technology is also reasonably resilient and can tolerate variations in influent flow rates without process upsets. The technology is, on a unit basis, more expensive than a package secondary plant (i.e. a sequencing batch reactor) followed by a direct filter. However given that satellite plants will often be located in areas where land is at a premium, the benefits of minimal footprint and smaller land requirements are likely to be significant decision criteria. The cost analysis developed in Section 7 is attempting to provide some conservatism by assuming the higher cost, smaller footprint unit. Once again, local agencies can modify the cost curves, using the templates included in the Appendix, to adjust for local conditions that may not place such a premium on small footprint.

Cost of land is also a site-specific factor that should be taken into account when performing cost analysis. Cost analysis will be discussed further in Section 7.

4.2 Utility Systems in Area

All package plants require connections to water and electrical systems. Water use at the plant would be primarily disinfected effluent and would place a minimal demand on the system that serves the area. The electrical load of the plant, however, may be more than the current electricity infrastructure can handle, especially if the plant is to be sited in a residential neighborhood. It is important to enter discussions with the electrical utility when considering a satellite plant because upgrades to the electrical system can prove to be a large addition to capital costs.

The cost curves presented in Section 7 assume that the electrical system serving the area is adequate. The cost curves do not make an allowance for a standby power supply because the satellite treatment plant is not a critical facility. Should the main power supply be interrupted, raw sewage would remain in the trunk sewer and recycled water would be temporarily unavailable.

4.3 Storage Needs

As discussed in Sections 2 and 3, above, wastewater flow and recycled water demand don't always occur at the same time. Satellite treatment plants will need to include some onsite storage in order to hold water that is produced during peak wastewater flows until it is needed.

Agencies will need to balance the need for storage with the water quality desires. Because recycled water often has a higher nutrient content than potable water, biological regrowth can be an issue in storage and distribution systems. The cost curves presented in Section 7 assume storage equal to 80% of demand. Some agencies and/or end users may prefer more than one day of storage and they may want to have supplies available in case of an extended period of time in which the demand for water surpasses the capacity of the satellite plant (for example, an extended heat wave that requires additional irrigation water).

4.4 Backup Water Supply Needs

In some instances where a steady water supply is critical, the district or the end user may want backup water supplies available if recycled water is not available. If a backup potable water supply is to be included as part of the storage and distribution system, it should be separated from the recycled water system with appropriate backflow prevention devices in accordance with State requirements (in California, State Requirements are found in the California Code of Regulations, Title 17) and the local water purveyor.

4.5 Solids Disposal

Onsite solids treatment can double the cost of a treatment plant, requires a large amount of operational attention, and creates odors. Generally, if onsite solids treatment is required, the prospect of a satellite treatment plant quickly becomes infeasible.

The ideal mechanism for solids disposal for a satellite plant is to route the solids back into the sanitary sewer to be processed at the main wastewater treatment plant. This solids disposal solution is very site sensitive. There must be sufficient flow in the sewer after the portion to be treated has been scalped to be able to keep the disposed solids in suspension and deliver them to the plant. Generally, the remaining wastewater should flow at 2 fps at all times to keep the solids flowing, or if the solids have settled, a minimum velocity of 5 fps is needed to re-suspend them.

Another alternative for solids disposal is to haul the solids to the central plant using trucks. This is less desirable than allowing the solids to go back into the sewer because it is more expensive and it causes truck traffic, potentially through residential neighborhoods.

4.6 Community Acceptability

Siting new wastewater facilities can be difficult, particularly in an established neighborhood. It is incumbent upon an agency to work with the local community during the planning and design period in order that “good neighbor” features are an intrinsic part of the facility. The following steps can be included as part of the outreach plan to include the affected community in the planning process.

1. Invite public participation in all critical decisions for a project, and provide ample opportunity for public input to be given directly to top project decision-makers;

2. Be flexible to adjusting plans, where feasible, to meet public needs and desires;

3. Keep the public to be directly impacted by the siting decision fully informed throughout the process;

4. Involve and incorporate community values into the project; and,

5. Engage and solicit the advice of nearby community members at every level and every stage, from planning and construction through operation of the proposed facility.

The facilities should be designed to eliminate any impacts for neighboring businesses or residents. Consideration should be given to the following:

- Containment of all noise-generating equipment inside an acoustically protected building
- Containment and scrubbing of all air inside the process building.
- Minimization of automatic yard lighting, i.e. use of manually operated lighting only when needed for nighttime operation rather than the typical photo-activated lighting.
- Minimization of truck deliveries, for example disposing of biosolids into the collection system, use of UV rather than sodium hypochlorite for disinfection
- Security features that blend into the neighborhood such as decorative fencing rather than chain-link fencing
- Use of buried reservoirs or pump stations rather than above-ground facilities
- Architectural style that is complementary to the context of the surrounding neighborhood.
- Landscaping that enhances the site and is compatible with neighboring landscaping
- Local building and zoning permitting requirements

Figure 6 illustrates an example satellite plant facility layout in which the treatment processes are contained within a building and the storage reservoir is located underground.

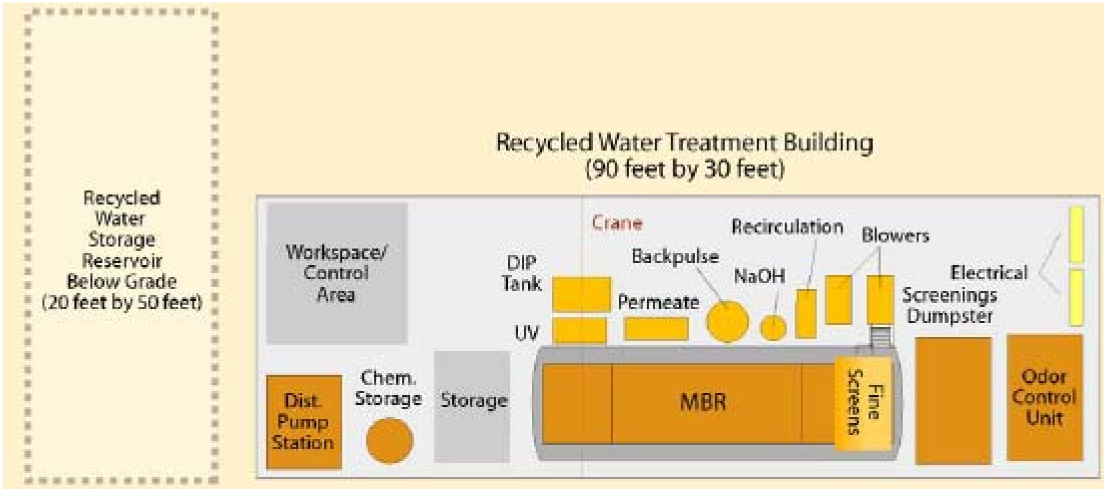


Figure 6 Example Layout for a 50,000 gpd Satellite Plant

The type of architectural treatment chosen for the containment structure should reflect the surrounding land uses, i.e. residential, industrial, or rural. The following figures are examples of the architectural treatments that have been used for other satellite plants.

Photo Credit – Oakwood Satellite Plant, Zenon Corp

Figure 7 Satellite Plant with Residential Style Architectural Treatment

Photo Credit – Westbrook Satellite Plant, Zenon Corp.

Figure 8 Satellite Plant with Rural Style Architectural Treatment

Photo Credit – Zenon Corporation

Figure 9 Satellite Plant in Industrial Area

Photo Credit – Powel River Satellite Plant, Zenon Corp.

Figure 10 Satellite Plant Housed Within Marina Building

Section 5 General Process Overview

5.1 Introduction

Section 2 of this study discussed the regulatory treatment standards established by the State of California for various recycled water demands. There are some uses with restricted public access such as irrigation of cemeteries or freeway medians that require treatment only to secondary disinfected levels. However, typical recycled water demands such as irrigation of parks, schools, and unrestricted access golf courses, or most industrial uses require treatment to a level defined as "Disinfected Tertiary Recycled Water" by the State Water Recycling Criteria.

Producing disinfected tertiary recycled water involves three process steps. The wastewater must first be oxidized. It then must be filtered and disinfected in accordance with guidelines established by the California Department of Health Services. These steps are illustrated in Figure 11.

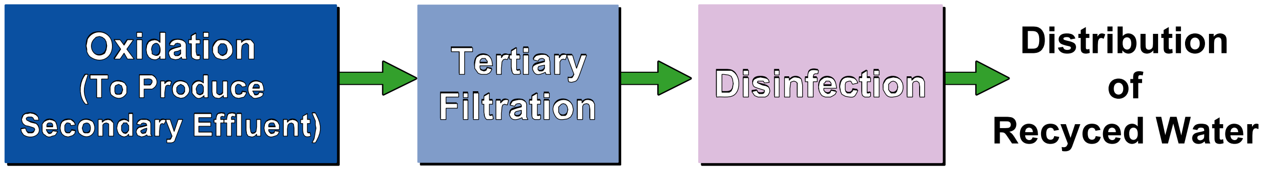


Figure 11 Conceptual Process Flow Train

In a traditional centralized approach to recycled water production, the oxidation step is accomplished at an existing secondary treatment plant and tertiary filtration and disinfection are added to the existing treatment train to produce recycled water. In a satellite treatment approach, the satellite plant must include not only the tertiary facilities, but also the oxidation step, i.e. it must first treat raw sewage to secondary treatment standards before the water is filtered and disinfected for recycling.

The following discussion describes alternatives for providing oxidation at a satellite treatment plant. It is followed by discussion of tertiary treatment alternatives for both filtration and disinfection.

5.2 Treatment to Secondary Levels

The State Water Recycling Criteria defines oxidized wastewater as "wastewater in which the organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen." This oxidation step is typically provided through traditional primary and secondary wastewater treatment. When providing recycled water from a centralized plant wastewater treatment plant, it is only necessary to consider the filtration and disinfection requirements. Since satellite treatment plants must treat raw wastewater to recycled water levels, they need to include this oxidation step.

Many package plants are available that can provide the primary and secondary treatment steps of the water recycling process. These include conventional activated sludge plants as well as other, less conventional technologies. The package plants can often be field assembled with construction on site limited to pouring a foundation pad, mounting the equipment, plumbing, supplying electricity, and providing a building to house the units.

5.2.1 Traditional Package Plants

Conventional activated sludge package plants have the same basic process train as many traditional activated sludge wastewater treatment plants. The equipment includes initial screening and solids removal followed by an aeration basin and secondary clarification basin, with a return activated sludge cycle. The process lowers BOD and TSS to levels that are acceptable for ultimate treatment through filtration and disinfection.

Other biological processes are available as package plants, with various advantages and disadvantages. These include extended aeration plants, sequencing batch reactors (SBRs), and oxidation ditches.

5.2.2 Emerging Package Plants

Many promising products are emerging to address specific perceived faults in the traditional package plant options. These include processes that are almost solely mechanical in order to lower energy costs and avoid the operational difficulty of maintaining a biological culture. There are also products that biologically treat wastewater in the root zone of aquatic plants, creating a greenhouse type of environment.

5.2.3 Package Plant Selection

The selection of package plant is very site specific. Factors such as land area, wastewater quality, and community acceptance will drive the selection as much as cost will.

5.3 Treatment to Tertiary Levels

The State of California Department of Health Services (DHS) has established the following standards for filtration and disinfection of recycled water.

> "The California Water Recycling Criteria (adopted December 2000) define Disinfected Tertiary Recycled Water as a wastewater, which has been oxidized and meets the following:

A. Has been coagulated* and passed through natural undisturbed soils or a bed of filter media pursuant to the following:

   1. At a rate that does not exceed 5 GPM/ft 2 in mono, dual or mixed media gravity or pressure filtration systems, or does not exceed 2 GPM/ft 2 in traveling bridge automatic backwash filters; and

   2. The turbidity does not exceed any of the following; a daily average of 2 NTU, 5 NTU more than 5% of the time within a 24-hour period, and 10 NTU at any time.

*Note: Coagulation may be waived if the filter effluent does not exceed 2 NTU, the filter influent is continuously measured, the filter influent turbidity does not exceed 5 NTU, and automatically activated chemical addition or diversion facilities are provided in the event filter effluent turbidity exceeds 5 NTU.

OR

B. Has been passed through a micro, nano., or R.O. membrane following which the turbidity does not exceed any of the following: 0.2 NTU more than 5% of the time within a 24-hour period and 0.5 NTU at any time.

AND

C. Has been disinfected by either:

   1. A chlorine disinfection process that provides a CT of 450 mg-min/l with a modal contact time of not less than 90 minutes based on peak dry weather flow, or

   2. A disinfection process that, when combined with filtration, has been demonstrated to achieve 5-log inactivation of virus."[4]

DHS considers a properly filtered and disinfected recycled water meeting the turbidity performance and coliform requirements outlined in the criteria to be essentially pathogen free. The treatment scheme is intended to remove solids (including some pathogens) and properly prepare the water for effective disinfection in order to achieve an approximately five-log reduction of virus.

5.3.1 Filtration:

Manufacturers of filtration equipment must submit pilot test data to DHS before their equipment is certified as an acceptable filtration technology under the State Water Recycling Criteria. In the certification letters for each technology DHS includes criteria such as allowable loading rates for the specific filtration equipment. There are four general types of filtration systems certified by DHS. They are:

- Granular media type filters
- Other media type filters
- Membrane Technologies
- Cloth Filters

Selection of the specific type of filter depends on site-specific issues such as capital and operating costs, availability, schedule, size, operator preference, etc. Filter performance on a given wastewater is dependent on the type of upstream treatment process, particle size distribution, particle charge, pH. In general, wastewaters with smaller particle size such as that from a trickling filter effluent, are more difficult to filter.

---

[4] State Of California Division Of Drinking Water And Environmental Management Treatment Technology Report For Recycled Water, August 2003

Filters for recycled water production generally are operated in a direct filtration mode. In this mode a chemical coagulant is mixed with the filter influent in the pipeline upstream of the filter. The coagulant helps the solids to flocculate resulting in solids that are larger and easier to filter. If the filter influent turbidity is below 5 ntu and the effluent turbidity is below 2 ntu, adding the coagulant chemical can be waived, although provisions for chemical addition are generally still provided in case the wastewater characteristics change.

If the water is more difficult to filter and the flocculation processes requires a longer residence time, more robust flocculation processes may be needed. These include having a separate upstream flocculation tank to enhance the flocculation process through slow mixing after the chemical addition or having a separate upstream flocculating clarifier in which the solids are flocculated and also settled out and removed from the process stream before the filter.

It is prudent that, at a minimum, bench scale filterability testing be done on the wastewater before selecting a particular filter type. This can be done by sending samples of the wastewater to the manufacturer's testing facilities where they will determine if the water can be filtered to meet the State Water Recycling Criteria, the type and dosage of chemicals needed to aid filtration, and the type of upstream flocculation that may be needed.

The following table summarizes the filter technologies that have been certified by DHS as of August 2003. This list is updated periodically as additional filtration technologies are certified. Updates are available from DHS.

Table 5 Filter Technologies Certified by DHS

Filter Type	Manufacturer
Granular Media	DynaSand (Parkson Corp)
	TechnaSand (WestTech Engineering)
	Hydro-Clear (U.S. Filter-Zimpro)
	ABW, Infilco-Degremont
	AquaABV (Aqua Aerobics Systems, Inc.)
	Tetra-Denit. (Tetra Technologies, Inc.)
	Centra Flow (Applied Process Technology)
	Fluidsand (Fluidyne, Corp)
	Hydrasand (Andritz Ruthner, Inc.)
	Strata-Sand (Ashbrook Corp)
Disc Filters	Aqua Disk (Aqua Aerobics Systems, Inc.)
Other Media Types	Fuzzy Filter (Schreiber LLC)
Membrane Technologies	Zenon Environmental Cycle-let, ZeeWeed/Zeno-gem, ZeeWeed 1000 UF
	US Filter/Memcor CMF (0.2 micron-PP and 0.1 micron-PVDF CMF Submerged (0.2 micron-PP and 0.1 micron-PVDF US Filter/Jet Tech

Filter Type	Manufacturer
	PALL Corporation
	Mitsubishi
	Kubota

5.3.2 Disinfection

The State Water Recycling Criteria lists the criteria for chlorine-based disinfection as a CT of 450 mg-min/l with a modal contact time of not less than 90 minutes based on peak dry weather flow. A baffling efficiency factor, typically 75%, is applied by DHS to the 90 minute modal contact time meaning, in practice, that a 120 minute theoretical contact time must be provided to meet the Title 22 requirement. Typically, chlorine-based disinfection systems use liquid sodium hypochlorite rather than gaseous chlorine for safety reasons. However, chlorine-based disinfection at a satellite plant can have several disadvantages:

- Relatively large footprint required for the chlorine contact basin
- Production of disinfection by-products (DBP) in particular trihalomethanes (THMs) and N-nitrosodimethylamine (NDMA)
- Periodic truck deliveries of sodium hypochlorite are required, approximately every two weeks depending on on-site storage volume required. Since satellite plants are often located in sensitive neighborhoods, transport and storage of hazardous chemicals is often unacceptable. On-site generation of sodium hypochlorite can be a possibility, but this increases the mechanical and operational complexity of the system and deliveries of supplies to generate the sodium hypochlorite are still needed.

The alternative disinfection process that has been accepted by DHS is disinfection by ultraviolet light. In December 2000, "Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse" were published by the National Water Research Institute (NWRI) and the American Water Works Association Research Foundation (AWWARF) in December 2000. DHS endorses these Guidelines and refers to them when evaluating UV disinfection proposals. Design of UV disinfection facilities therefore needs to be done in accordance with the NWRI Guidelines.

As with the filtration technologies, DHS has certified specific UV manufacturers and equipment for Title 22 compliance, provided the design is done in accordance with NWRI guidelines. Also as with filtration, the following list is updated periodically as additional UV technologies are certified and updates are available from DHS. Table 6 outlines the currently approved technologies.

Table 6 UV Technologies Certified by DHS

UV Equipment Manufacturers
Trojan Technologies
PCI-Wedeco
Wedeco-Ideal Horizons
Aquionics
Ultraguard (Service Systems)
Aquaray (Infilco-Degremont)
Ultra Tech

5.3.3 Membrane Bioreactors

One of the California DHS approved technologies, the membrane bioreactor (MBR), belongs to its own category of treatment processes. In the MBR process the unit processes of aeration, clarification, and filtration are combined into one process. An MBR package, approved by DHS, meets the requirements for both secondary and tertiary treatment. It needs to be preceded with preliminary fine screening. The aeration process takes place in the bioreactor, stabilizing and lowering the BOD of the wastewater. The traditional clarifier step is skipped, and the water is pulled via a suction pump directly through ultrafiltration membranes that are submerged in the mixed liquor. The membranes provide for both the solid/liquid separation step usually carried out by clarifiers and the filtration step required for recycled water use. It is possible to configure the tank to provide for nutrient removal as well. The resulting effluent meets State Water Recycling Criteria requirements for tertiary treated water and needs only to be disinfected for use as recycled water.

Because the MBR is essentially a complete “package” in itself, the cost curves in Section 7 are based on this process.

5.4 Treatment Technology Comparison

As was discussed in Section 5.1, the process that must be undergone in a satellite treatment facility is a three-step process. Step 1 is treatment to the secondary treatment level. Step 2 is filtration, and Step 3 is disinfection. The technologies available for satellite treatment vary widely in cost and footprint. They also vary greatly in their energy usage. Table 7 represents some of the technologies and compares them in terms of capital equipment cost, energy use, and footprint. The technologies are organized by the treatment level that they achieve. Note that a complete satellite plant has equipment that achieve all three steps. The costs presented in this table are only equipment costs and are presented for comparison amongst each other. Section 7 of this TM has a more detailed cost analysis technique.

Table 7 Treatment Technology Summary

Level of Treatment Achieved	Step	Process	Type of Equipment	Equipment Cost ($/mgd)[1,2]	Energy Used (kWh/mgd)[1]	Footprint (sq feet)[1]
Filtered Water	1	Secondary Plant	Sequencing Batch Reactor (SBR)	$580,000	1330	10,000
			Activated Sludge Package Plant	$920,000	3220	22,000
			Natural Treatment System[3]	$4,040,000	2200	20,000
	2	Title 22 Filter	Continuous Backwash	$540,000	450	1,600
			Disc Filter	$530,000	4	1,300
	1 and 2	Combined Processes	Membrane Bioreactor	$1,600,000	790	15,000
			Physical/ Chemical System[4]	$2,280,000	6120	3,200
Disinfected Water	3	Chemical	Sodium Hypochlorite	$124,000	20	4,000
		Non-chemical	UV	$720,000	580	160

[1] Costs and footprint have been normalized from equipment quotes of various sized systems and my not accurately reflect economies of scale

[2] Eqipment cost does not include allowances for construction, electrical, yard piping, engineering, contractor's O&P, etc. and are only provided for comparison amongst each other

[3] Data based on ARZ-IFAS Living Machine® System. This is an alternative technology, and it has yet to be determined how well it will comply with DHS Title 22 requirements. See Appendix C for product information.

[4] Data based on Great Circle Water, Inc. System. This is an alternative technology that is currently undergoing DHS Title 22 testing. See Appendix C for product information.

Section 6 General Distribution System Overview

This Distribution System overview is intended to provide general guidance for developing a recycled water distribution system from the satellite treatment facility and also for developing the main extensions from the centralized wastewater treatment plant. It also provides context for interpreting the cost curves presented in the subsequent sections. In some jurisdictions, the main extension from the centralized plant may be technically classified as a “transmission main”. However given the sizing assumptions and definitions outlined in Section 1 of this Technical Memorandum, this main extension will be relatively small diameter (10-inches or less) and can be planned and estimated using the same criteria as distribution system piping.

This distribution system overview is intended to cover those facilities located in public rights-of-way and operated and maintained by the public agency. Recycled water system facilities located on private property (“onsite facilities”) are regulated by the State Water Recycling Criteria.[5] Before connecting new users, a local agency must file an Engineering Report with Department of Health Services describing the onsite facilities and the methods used to comply with the State Water Recycling Criteria. These site specific criteria are not included in this discussion.

In general, distribution systems for recycled water will be designed according to technical standards that are similar to the standards for a potable water system, because the recycled water system is intended to provide the same type of service. Well-codified criteria are available from the Irvine Ranch Water District[6]. The additional considerations presented below incorporate planning criteria and or operational experience gleaned from North Bay Watershed Association Member agencies.

6.1 Pipeline Considerations

In general recycled water distribution system piping is designed as pressurized water piping. Common requirements that reflect the State Water Recycling Criteria, and are found in local agency’s published criteria include the following:

- Pipelines are 4-inch diameter or larger and looped.
- Distribution piping is sized to maintain velocities of 4 to 8 feet per second.
- Pipelines are C-900 PVC, Class 150 or 200 and colored purple.
- Pipelines are separated from the potable water line by 1-vertical foot and 4-horizontal feet.
- Water services are also colored purple or continuously wrapped in purple marking tape.

6.2 Pumping System Considerations

For a satellite treatment facility, the recycled water pump station needs to maintain acceptable system pressures. Since users will frequently be converting from the potable water system, distribution system pressures of 40psi-80psi are generally considered in the acceptable range.

The basic configuration of the recycled water facilities can affect the sizing of pumps and the energy costs associated with pumping. Figure 3 presented earlier in this Technical Memorandum illustrates a conceptual satellite water recycling facility located on a single site. In this case, the recycled water pump station must maintain system pressures on demand. Energy demands will be variable and the local agency will need to budget its energy costs at peak rates.

An alternative configuration would utilize a recycled water storage reservoir located at an appropriate elevation to supply water at system pressure by gravity. In this case, the recycled water pump station delivers water based on tank level rather than system demand. Pumping can occur over controlled periods and the local agency may be able take advantage of off-peak energy rates. The single largest difficulty with this configuration is that a local agency must locate two sites (one for treatment and one for storage) instead of a single site.

The cost curves presented in Section 7 assume the configuration presented in Figure 3.

---

[5] California Code of Regulations, Title 22 Section 60301 et. seq.

[6] www/irwd.com/water service/developer services/IRWD Procedural Guidelines and General Design Requirements, Section 5 Design Criteria Recycled Water Facilities.

6.3 Storage Considerations

As noted above, recycled water storage is a necessary feature for both satellite and centralized facilities because the wastewater production rate does not usually match the recycled water demand rate. However, since the recycled water is a supplemental supply, and potable water or raw water is typically also available, it is not necessary to design recycled water storage systems to the same criteria as potable water systems, where stored water is often the only protection against power outage or emergency demand. Anecdotal information from water agencies' operating recycled water systems indicates that because of the nutrient quality of recycled water, which can support biological regrowth, long storage retention times can adversely affect the quality of delivered recycled water.[7]

A brief review of the storage system design criteria for North Bay Watershed Association member agencies yielded designs that included no system storage (all storage provided onsite by the customer) to criteria varying from 65% to approximately 85% of daily demand.[8] In performing its initial screening, a local agency needs to understand its customers' demand patterns in order to account for appropriate system storage. The cost curves included in Section 7 assumes recycled water storage at 80% of the daily demand for both the satellite and centralized water recycling facilities. This assumption is on the conservative side for costing purposes.

6.4 Water Quality Considerations

As noted several times in this Technical Memoranda, recycled water quality can degrade within a distribution system much more quickly than potable water quality degrades. While recycled water purveyors are required to monitor bacteriological water quality as it leaves the treatment plant, there are not codified requirements for water quality or water quality monitoring within the distribution system. However, mature water recycling agencies have developed operational practices that include distribution system monitoring at storage reservoirs and key user sites on a weekly basis.[9] These agencies also indicate that charging the recycled water distribution system with potable water, during low demand periods improves the overall water quality performance of the system.

Section 7 Preliminary Economic Evaluation Techniques

7.1 Introduction

This section of Technical Memorandum presents the cost estimating system that will be used to evaluate candidate sites in each of the water service areas under study. The cost information developed here is somewhat general in nature in order to allow local agencies to perform screening analysis for the satellite treatment plant concept prior to investing in preliminary design activities.

The final costs of any project will depend on actual labor and material costs, competitive market conditions, final project costs, implementation schedule, and other variable factors. As a result, the final project costs will likely vary from initial estimate developed from the curves presented here.

The cost estimating approach used is based on guidelines developed by the American Association of Cost Engineers (AACE). During the 1970s, the American Association of Cost Engineers developed definitions for levels of accuracy commonly used by professional cost estimators. The AACE defined the three levels of cost estimates as *order-of-magnitude, budget,* and *definitive*

---

[7] Marin Municipal Water District, personal communication.

[8] North Marin Water District and Marin Municipal Water District.

[9] Irvine Ranch Water District and Marin Municipal Water District, personal communication.

estimates. The cost curves presented here will yield order-of magnitude estimates, as defined below.

7.2 Order-of-Magnitude Cost Estimates

An order-of-magnitude estimate is made without detailed engineering data. Some examples include:

- An estimate from cost capacity curves
- An estimate using scale-up or scale-down factors
- An approximate ratio estimate

Typically, an order-of-magnitude estimate is prepared *at the end of the schematic design phase* of the design delivery process. It is normally expected that an estimate of this type would be accurate within plus 50 percent to minus 30 percent of the estimated cost. For example, if the estimated cost of an order-of-magnitude estimate is $1 million, then application of the plus-50-percent to minus-30-percent accuracy range would be appropriate. The plus-50-percent accuracy range means that the estimate may increase by 50 percent or that the actual cost may be up to 50 percent higher than the estimated cost. Similarly, the minus-30-percent accuracy range means that the estimated cost could be overstated by 30 percent or the actual cost may be 30 percent lower than the estimated cost. The range of expected costs in this instance would range from $.7 million to $1.5 million.

Because of the necessarily general nature of this analysis, local agencies may wish to consider the Benefit Cost Ratios they develop as having a “band of accuracy” essentially within plus 50% to minus 30%. This would mean that satellite water recycling plants, presenting Benefit Cost Ratios within the band 0.7 to 1.5 are potentially feasible.

7.3 Capital Cost Curves

Capital Cost Curves have been developed for the Satellite Water Recycling Plant, the Centralized Water Recycling Plant upgrade and for distribution system piping extension to the satellite site. These curves are presented as Figures 12, 13 and 14 respectively.

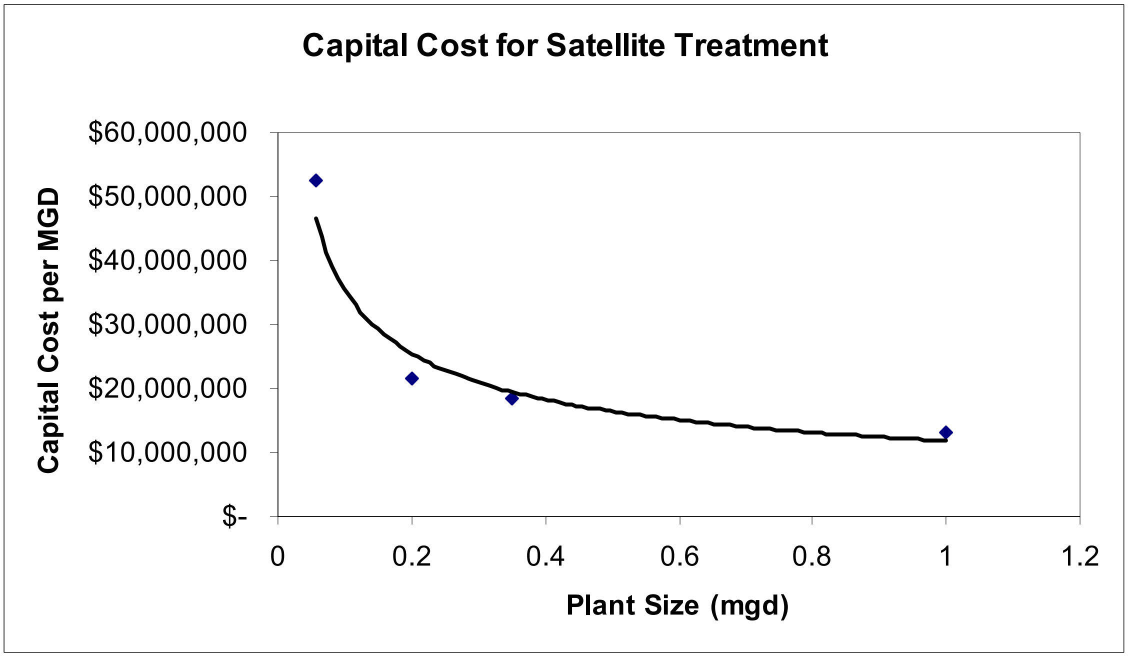


Figure 12 Capital Cost for Satellite Plant

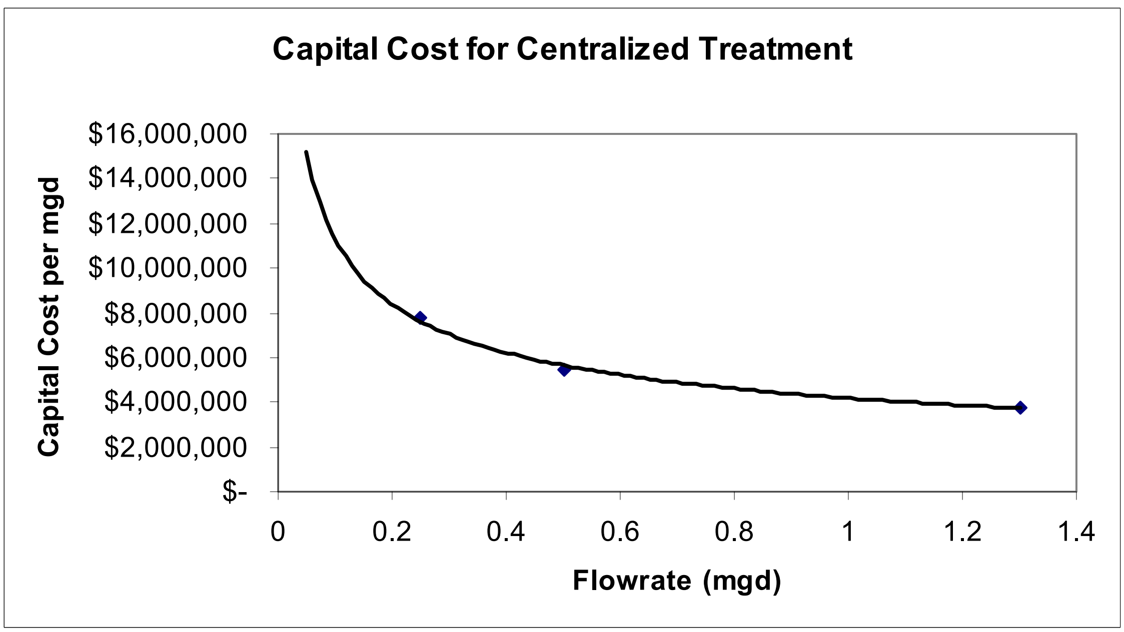


Figure 13 Capital Cost for Centralized Treatment

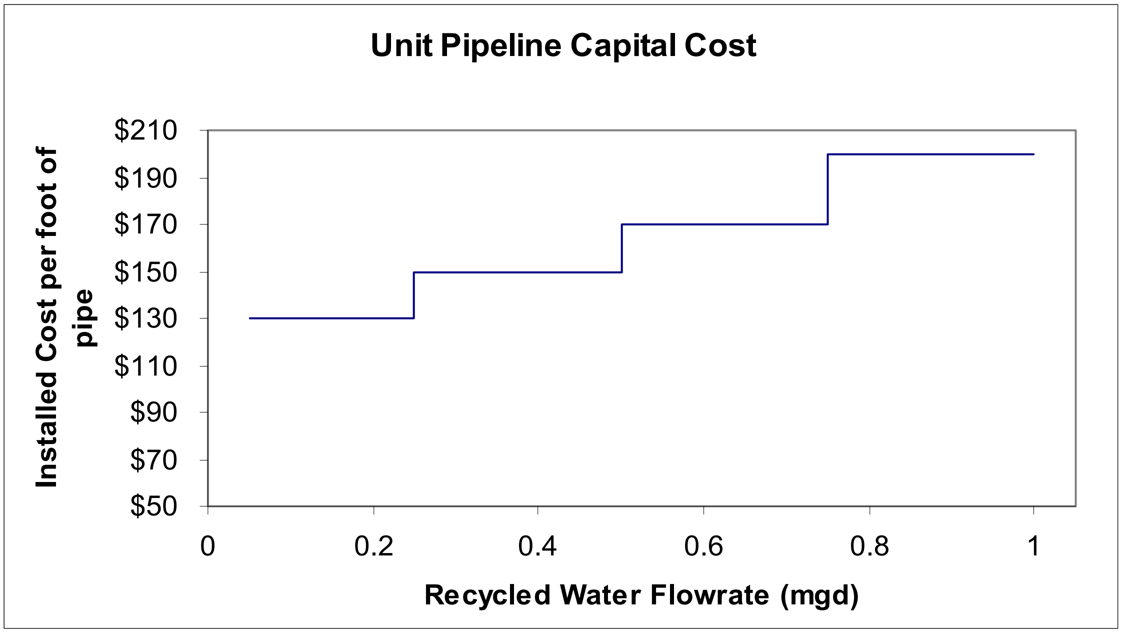


Figure 14 Unit Pipeline Capital Cost

The purpose of these cost curves is to allow an agency that knows both the water demand it is trying to satisfy and the distance between the central plant and the demand to quickly develop comparative estimates for screening purposes. The estimating templates used to develop these curves are included in the Appendix to this Technical Memorandum. A brief description of assumptions and application techniques follows.

7.3.1 Assumptions for the Satellite Water Recycling Facility:

The cost curve presented for the Satellite Water Recycling Facility includes the following items:

- A feedwell pump station from the sanitary sewer
- Screening
- A Membrane Bioreactor to provide secondary and tertiary treatment
- Ultraviolet Disinfection
- Solids return to the sanitary sewer
- An enclosing building for the treatment process train
- Power, instrumentation, controls
- Process chemical storage and feed
- A recycled water storage tank sized for 80% of plant capacity
- A recycled water pump station
- An allowance for landscaping

Equipment costs are based on vendor quotes for a range of flows. The building is estimated at $200 per square foot and the storage tank is estimated at $1 per gallon.

Raw costs have been escalated to account for planning, design, construction inspection, site work and installation and appropriate sales tax.

The costs presented do not include land acquisition.

7.3.2 Assumptions for the Centralized Water Recycling Facility:

The cost curve presented for the Central Water Recycling Facility includes the following items:

- A granular media direct filtration unit
- Ultraviolet Disinfection
- Power, instrumentation, controls
- Process chemical storage and feed
- A recycled water storage tank sized for 80% of the filter capacity
- A recycled water pump station
- An allowance for modest landscaping

Equipment costs are based on vendor quotes for a range of flows. The storage tank is estimated at $1 per gallon.

Raw costs have been escalated to account for planning, design, construction inspection, site work and installation and appropriate sales tax.

The costs presented do not include land acquisition. It is assumed that land is available at the central facility. The costs also do not include salt removal for those plants in which the total dissolved solids of the effluent are too high to be used for the identified water needs. In those cases, a salt removal process such as reverse osmosis would need to be added to the recycled water facility.

7.3.3 Assumptions for Distribution Piping Extension

The cost curve presented for the distribution piping facility assumes pipe diameter varies with flow rate, as shown in Table 8. The curve is a step curve.

Table 8 Pipeline Size Assumptions

Facility Size (mgd)	Pipeline Size Assumption
0 – 0.25 mgd	4-inch
0.26 – 0.5 mgd	6-inch
0.51 – 0.75 mgd	8-inch
0.76 – 1 mgd	10-inch

Costs are based recent bid prices for pipeline installation as well as “Current Construction Costs 2003” from Saylor Publications for PVC pipe constructed along paved roads in an urban setting. They include allowances for planning, design, construction inspection, site work and installation.

The costs presented do not include land acquisition. It is assumed that land is available within a public right-of-way.

7.3.4 On-site Retrofit of Customer’s Water Service

There is cost and time involved in converting a customer’s irrigation services from potable to recycled water. These costs are not included in the cost curves presented in Section 7, but should be considered when making an overall evaluation of the feasibility of recycled water.

This section documents the efforts of Marin Municipal Water District in making such conversions, and is indicative of the effort that can be required.

> "Time and effort to convert a site is independent of the size of the site. It frequently requires as much time and effort to convert a small site as a large one. Tasks involved in this effort include the following:
>
> - Initial customer contact and check of records.
> - Initial site visit and plumbing system inspection.
> - Develop plan and scope of work to separate potable and non-potable systems.
> - Deliver plan and scope to customer and assist with selection of contractor to perform work on customers' side of meter (system separation, backflow prevention device, expansion tank, and irrigation system modifications to satisfy "no overspray and no run-off" regulatory requirements.
> - Place work order to have recycled water meter set.
> - Inspect contractor work on customers' piping.
> - Perform cross connection shut-down test to verify separation of potable and non-potable systems. Perform final tie-in upon successful test.
> - Finalize drawings and records to as-built
>
> **Estimated Costs to water agency:**
>
> - Staff time 40 hrs @ $50/hr = $2000 per site
> - Install 1-inch recycled water meter and service connection = $1,750
>
> **Estimated Cost to customer:**
>
> - Install 1-inch RP device on potable line, testing, and expansion tank = $1,500
>
> **Regulatory Requirements for Dual-Plumbed Sites**
>
> - For "dual-plumbed" sites, CA DHS regulations require inspections annually and cross connection tests once every 4 years. "Dual-plumbed" sites consist of irrigation at individual residences and buildings that use recycled water for toilet flushing.
> - Annual inspections require 2 hours to schedule and perform: 3 hrs @$50/hr = $150 per site.
> - Cross connection testing and follow-up report to CA DHS requires an additional 4 hrs @ $50/hr = $200 every 4 years."[10]

7.3.5 Application of the Cost Curves:

The cost curves can be used to arrive at order-of magnitude capital estimates using the following for formulas:

For the Satellite Facility = **Cost/MGD (from Figure 7) x MGD proposed**
+ (Cost/Ft of Pipe (from Figure 9) x Feet Required by Project

[10] Communication from Bob Castle, Marin Municipal Water District

For the Central Facility Expansion= Cost/MGD (from Figure 8) x MGD proposed
+ (Cost/Ft of Pipe (from Figure 9) x Feet Required by Project

7.4 Operational Cost Curves

The operational cost curves presented above were developed to allow for comparative O&M estimates rather than total O&M estimates. The operational cost curves reflect the difference in energy costs between pumping from a centralized facility to remote area rather the pumping from the satellite facility directly into the recycled water distribution system. For this order-of-magnitude estimate, the assumption is that the treatment process costs (manpower, chemicals, sampling and process power) are roughly equivalent at the satellite and the centralized facility. Note that interagency agreements between the water and the wastewater agency are needed for ownership and operation of the recycled water plant. A state certified wastewater operator is needed for operation of the recycled water plant. If the water agency rather than the wastewater agency operates the satellite plant, the inter-agency agreement should include provisions to provide certified wastewater operators on a part-time basis. Otherwise the water agency will need to cross-certify a water plant operator or hire a contract operator.

Distribution system delivery pressure assumed to be 70 psi. Headloss is assumed to be 5-feet per 1000-feet of pipeline. For calculating pump motor horsepower it is necessary to assume a distribution pipeline length. The satellite facility is assumed to be located no more that 0.5 miles from its service area. The central facility is assumed to be 5 miles from its service area.

Electricity is estimated to cost $0.15/kWh.

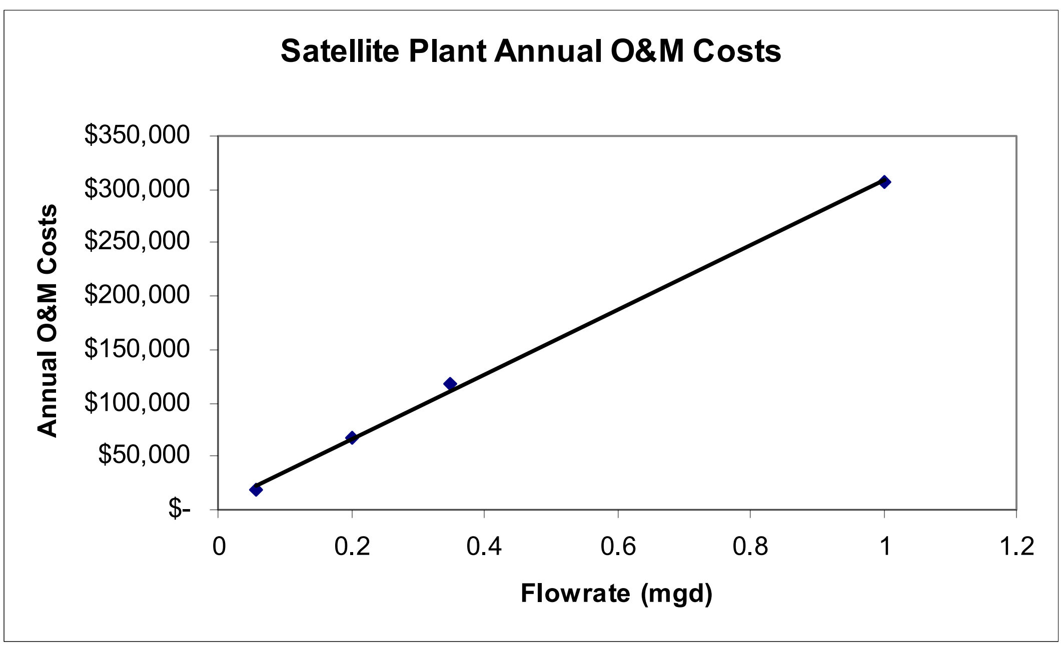


Figure 15 Satellite Plant Annual O&M Costs

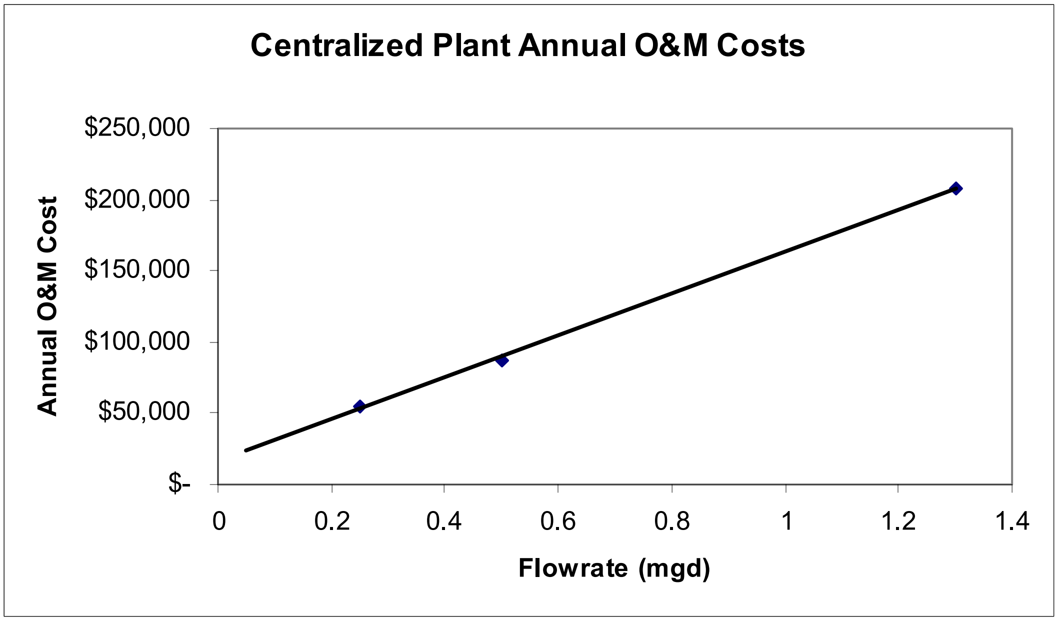


Figure 16 Centralized Plant Annual O&M Costs

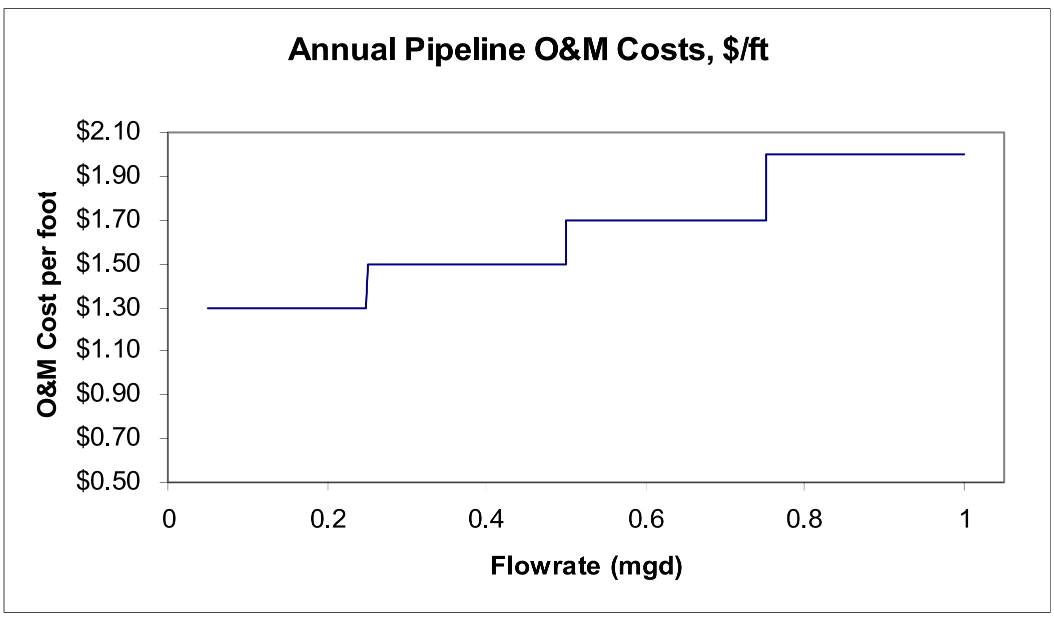


Figure 17 Pipeline Annual O&M Costs, $/ft

As a result of this analysis, it can generally be assumed that satellite facilities become economically feasible if they are approximately four miles away from the central plant. Otherwise central treatment and distribution are more feasible.

7.5 Economic Evaluation Techniques

As indicated in Figure 2 (The Decision Process Flow Chart), the screening process associated with evaluating the costs of a satellite recycled water facility as a water supply includes two cost comparisons. First a satellite water recycling facility is compared to extending service from a central water recycling facility and then the more cost effective recycled water source is compared to developing the necessary increment of potable water infrastructure.

The Department of Water Resources, which is providing funding assistance for this study, has developed tables intended to assist in the economic comparison of various alternative projects. These tables are included in Appendix B. Appendix B also provides guidance on using the cost information presented in Section 7 to complete the tables for the Satellite versus Central Recycling system.

Appendix A
Cost Estimating Templates

NBWA Satellite Treatment Plant Study
Satellite Plant Estimate

Item	Quantity	Unit	Unit Cost	Subtotal	Sales Tax 8.25%	Subtotal	Tech. Allowance 82.5%	Subtotal	Imp. Allowance 35.0%	Total Cap. Cost	Annual O&M Cost	Ammortized Cost per AF (30 years @ 6%)	O&M Cost per AF	Total Cost per AF
Processing Rate in mgd	0.056													
Influent Pump Station	1	LS	$ 5,000	$ 5,000										
Package Treatment System	56,000	GAL	$ 12.07	$ 676,000										
Utility Building	2,000	SF	$ 200	$ 400,000										
Recycled Water Storage	44,800	GAL	$ 0.80	$ 36,000										
Recycled Water Pump Station	1	LS	$ 21,000	$ 21,000										
Site Landscaping	1	LS	$ 10,000	$ 10,000										
Subtotal				*$ 1,148,000*	*$ 45,000*	*$ 1,193,000*	*$ 984,000*	*$ 2,177,000*	*$ 762,000*	*$ 2,939,000*	$ 19,000.00	$ 7,100.00	$ 600.00	$ 7,700.00
Item	**Quantity**	**Unit**	**Unit Cost**	**Subtotal**	**Sales Tax 8.25%**	**Subtotal**	**Tech. Allowance 82.5%**	**Subtotal**	**Imp. Allowance 35.0%**	**Total Cap. Cost**	**Annual O&M Cost**	**Ammortized Cost per AF (30 years @ 6%)**	**O&M Cost per AF**	**Total Cost per AF**
Processing Rate in mgd	0.200													
Influent Pump Station	1	LS	$ 11,000	$ 11,000										
Package Treatment System	200,000	GAL	$ 3.93	$ 786,000										
Utility Building	3,500	SF	$ 200	$ 700,000										
Recycled Water Storage	160,000	GAL	$ 0.80	$ 128,000										
Recycled Water Pump Station	1	LS	$ 52,000	$ 52,000										
Site Landscaping	1	LS	$ 10,000	$ 10,000										
Subtotal				*$ 1,687,000*	*$ 52,000*	*$ 1,739,000*	*$ 1,435,000*	*$ 3,174,000*	*$ 1,111,000*	*$ 4,285,000*	$ 67,000.00	$ 3,100.00	$ 700.00	$ 3,800.00
Item	**Quantity**	**Unit**	**Unit Cost**	**Subtotal**	**Sales Tax 8.25%**	**Subtotal**	**Tech. Allowance 82.5%**	**Subtotal**	**Imp. Allowance 35.0%**	**Total Cap. Cost**	**Annual O&M Cost**	**Ammortized Cost per AF (30 years @ 6%)**	**O&M Cost per AF**	**Total Cost per AF**
Processing Rate in mgd	0.350													
Influent Pump Station	1	LS	$ 11,000	$ 11,000										
Package Treatment System	350,000	GAL	$ 3.45	$ 1,208,000										
Utility Building	5,000	SF	$ 200	$ 1,000,000										
Recycled Water Storage	280,000	GAL	$ 0.80	$ 224,000										
Recycled Water Pump Station	1	LS	$ 77,000	$ 77,000										
Site Landscaping	1	LS	$ 10,000	$ 10,000										
Subtotal				*$ 2,530,000*	*$ 80,000*	*$ 2,610,000*	*$ 2,153,000*	*$ 4,763,000*	*$ 1,667,000*	*$ 6,430,000*	$ 118,000.00	$ 2,600.00	$ 700.00	$ 3,300.00
Item	**Quantity**	**Unit**	**Unit Cost**	**Subtotal**	**Sales Tax 8.25%**	**Subtotal**	**Tech. Allowance 82.5%**	**Subtotal**	**Imp. Allowance 35.0%**	**Total Cap. Cost**	**Annual O&M Cost**	**Ammortized Cost per AF (30 years @ 6%)**	**O&M Cost per AF**	**Total Cost per AF**
Processing Rate in mgd	1.000													
Feedwell Pump Station	1	LS	$ 27,000	$ 27,000										
Package Treatment System	1,000,000	GAL	$ 2.73	$ 2,734,000										
Utility Building	8,300	SF	$ 200	$ 1,660,000										
Recycled Water Storage	800,000	GAL	$ 0.80	$ 640,000										
Recycled Water Pump Station	1	LS	$ 113,000	$ 113,000										
Site Landscaping	1	LS	$ 10,000	$ 10,000										
Subtotal				*$ 5,184,000*	*$ 180,000*	*$ 5,364,000*	*$ 4,425,000*	*$ 9,789,000*	*$ 3,426,000*	*$ 13,215,000*	$ 307,000.00	$ 1,800.00	$ 600.00	$ 2,400.00

NBWA Satellite Treatment Plant Study
Centralized Plant Estimate

Item	Quantity	Unit	Unit Cost	Subtotal	Sales Tax 8.25%	Subtotal	Tech. Allowance 82.5%	Subtotal	Imp. Allowance 35.0%	Total Cap. Cost	Annual O&M Cost	Ammortized Cost per AF (30 years @ 6%)	O&M Cost per AF	Total Cost per AF
Processing Rate in mgd	0.250													
Influent Pump Station	1	LS	$ 11,000.00	$ 11,000										
Filtration and Disinfection	250,000	GAL	$ 1.76	$ 440,000										
Blower/Electrical Building	360	SF	$ 200.00	$ 72,000										
Recycled Water Storage	200,000	GAL	$ 0.80	$ 160,000										
Recycled Water Pump Station	1	LS	$ 77,000.00	$ 77,000										
Site Landscaping	1	LS	$ 5,000.00	$ 5,000										
Subtotal				*$ 765,000*	*$ 22,000*	*$ 787,000*	*$ 649,000*	*$ 1,436,000*	*$ 503,000*	*$ 1,939,000*	$ 55,000.00	$ 1,500.00	$ 400.00	$ 1,900.00

Item	Quantity	Unit	Unit Cost	Subtotal	Sales Tax 8.25%	Subtotal	Tech. Allowance 82.5%	Subtotal	Imp. Allowance 35.0%	Total Cap. Cost	Annual O&M Cost	Ammortized Cost per AF (30 years @ 6%)	O&M Cost per AF	Total Cost per AF
Processing Rate in mgd	0.500													
Influent Pump Station	1	LS	$ 11,000.00	$ 11,000										
Filtration and Disinfection	500,000	GAL	$ 1.12	$ 559,000										
Blower/Electrical Building	360	SF	$ 200.00	$ 72,000										
Recycled Water Storage	400,000	GAL	$ 0.80	$ 320,000										
Recycled Water Pump Station	1	LS	$ 113,000.00	$ 113,000										
Site Landscaping	1	LS	$ 5,000.00	$ 5,000										
Subtotal				*$ 1,080,000*	*$ 28,000*	*$ 1,108,000*	*$ 914,000*	*$ 2,022,000*	*$ 708,000*	*$ 2,730,000*	$ 87,000.00	$ 800.00	$ 300.00	$ 1,100.00

Item	Quantity	Unit	Unit Cost	Subtotal	Sales Tax 8.25%	Subtotal	Tech. Allowance 82.5%	Subtotal	Imp. Allowance 35.0%	Total Cap. Cost	Annual O&M Cost	Ammortized Cost per AF (30 years @ 6%)	O&M Cost per AF	Total Cost per AF
Processing Rate in mgd	1.300													
Influent Pump Station	1	LS	$ 27,000.00	$ 27,000										
Filtration and Disinfection	1,300,000	GAL	$ 0.64	$ 832,000										
Blower/Electrical Building	420	SF	$ 200.00	$ 84,000										
Recycled Water Storage	1,040,000	GAL	$ 0.80	$ 832,000										
Recycled Water Pump Station	1	LS	$ 178,000.00	$ 178,000										
Site Landscaping	1	LS	$ 5,000.00	$ 5,000										
Subtotal				*$ 1,958,000*	*$ 41,000*	*$ 1,999,000*	*$ 1,649,000*	*$ 3,648,000*	*$ 1,277,000*	*$ 4,925,000*	$ 208,000.00	$ 500.00	$ 300.00	$ 800.00

Appendix B
DWR Economic Tables

The Department of Water Resources, which is providing funding assistance for this study, has developed tables intended to assist in the economic comparison of various alternative projects. These tables are included in Appendix B. Appendix B also provides guidance on using the cost information presented in Section 7 to complete the tables for the Satellite versus Central Recycling system.

1. Satellite versus Centralized Recycling Systems

This comparison is completed first in order to identify the most cost effective recycling alternative.

Table 1 Project Performance: enter the demand proposed to be met by recycled water. This information is ultimately used to calculate the cost of new water supply and is often utilized by State and Federal funding agencies to evaluate projects.

Table 2 Capital Costs: this table is completed for the proposed Satellite Facility. Local agencies have the opportunity to enter land costs (Row 1). Other project costs are included in the Capital Cost pulled from the Cost Curve above and include a contingency. The table allows a local agency to include appropriate overhead, legal and site specific costs. These should also be included for the Centralized Facility.

Table 3 Operations & Maintenance Costs: this table is also completed for the proposed Satellite Facility. Annual Operations & Maintenance can be pulled from the Cost Curve. The table allows a local agency to include appropriate administration and other site specific costs. These same costs should also be included for the Centralized Facility. The table calculations allow an agency to discount the stream of annual costs (over 50 years) and arrive at a net present worth for this stream of expenditures.

Table 4 Total Cost Summary: This table utilizes the capital cost and the net present worth of the operational costs to calculate a total net present cost of the project.

Table 5a Avoided Costs of Current Supply Sources: This table should not be used when comparing the two recycled water sources. It can be used in the next section which compares the preferred recycled water source to a potable source.

Table 5b Avoided Costs of Future Supply Sources: This table should be completed for the Centralized Water Recycling facility. Base Capital and Operational Costs can be pulled from the Cost Curves. A local agency should remember to add land costs (if appropriate) and other overhead and site specific costs in order to develop a fair comparison with the Satellite Recycling Facility budgets developed in Tables 2 and 3.

Table 5c Water Sales Revenue: In general, this table should not be used when comparing the two recycled water sources because the two sources of water should be equally "vendible". (i.e. the local agency is likely to apply the same pricing structure to recycled water regardless of whether it is produced at the central or satellite facility).

Table 5d Total Water Supply Benefits: This table uses information generated in Tables 5a through 5c to calculate the net present benefits of the project.

Table 6 Benefit/Cost Ratio: This table compares Benefits to Costs. In theory, a Benefit/Cost Ratio of greater than 1 indicates that the satellite source is the preferable source of recycled water. Remembering that the costs curves utilize order-of-magnitude estimating techniques, an agency may wish to consider a "band of accuracy" in the B/C ratios where a ratio of less than 0.7 clearly favors centralized recycling; a ratio of greater than 1.5 clearly favors a satellite facility and ratios between 0.7 and 1.5 indicate that the two facilities have a comparable magnitude of cost. Within this accuracy band, other non-economic factors could be used to make a decision. These factors might include neighborhood sensitivity, a policy preference to have new development areas locally manage their resource demands or a policy preference to increase overall system reliability through decentralization.

2. Recycled Water versus Potable/Raw Water

Once the preferred recycled water source is selected, it can be compared against the other available water sources available to an agency. Essentially the same tables are used, but more factors can influence the completion of Tables 5a, 5b and 5c.

Tables 1 through 4: These tables can be completed exactly as described above, using the appropriate cost curves for the preferred recycled water source and adding appropriate local allowances for land, agency overhead and other site specific costs.

Table 5a Avoided Costs of Current Supply Sources: If the recycled water source will not only meet new demands but offset a portion of the current demand, this benefit should be accounted for. In general the current cost of supplying water should include the cost to produce the water and deliver it to the service area in question. These costs can generally be derived from water rates (wholesale or retail) and local capacity or connection fees. In accounting for these avoided costs, agencies should be careful to recognize that the proposed recycled water system includes increments of storage and distribution system capacity, that "free-up" and equivalent capacity in the potable water system. This means even if the recycled water supply is replacing a current source (it's only meeting new demand), it may still be "returning" distribution and storage capacity to the potable water system. The value of this returned capacity should be credited as a benefit. Some agencies may also be able to resell the potable water connection fee if a customer converts to recycled water use. That is an example of a site-specific factor that is not included in the DWR tables.

It should be noted here that the DWR tables do not account for avoided costs associated with wastewater treatment. If, for example, a wastewater agency must limit the mass of metals discharged, this could be accomplished by a recycled water program in lieu of treatment plant upgrades. The avoided cost of additional wastewater treatment then becomes a monetary benefit for the recycled water program. This benefit is very site-specific and agencies using the DWR tables to evaluate cost-effectiveness should include avoided costs of wastewater treatment if appropriate for their area.

Table 5b Avoided Costs of Future Supply Sources: Typically the satellite water recycling facility analysis is undertaken because an agency needs to develop a new water supply source. Table 5b should be completed with the best possible information on the cost of developing and operating this new source.

If, as can be the case in California, the new or expanded water source is viewed as valuable for environmental or recreational reasons, cover the costs of these values in Table 5b. Resource agencies and environmental groups have begun to develop this economic data and sources include the following:

- National Park Service, Rivers Trails and Conservation Assistance Program, "Economic Impacts of Protecting Rivers, Trails and Greenway Corridors", Washington D.C.
- Dolcino, Chiara and Anderson Stephen, "River Valuation Bibliography", privately published (703) 836-6149.
- US Fish & Wildlife Service, Ecology Research Center, "An Annotated Bibliography of Economic Literature on Instream Flow", Fort Collins, CO.

If, as can also be the case in California, the new or expanded water source isn't obviously available, cover the costs of constrained land and water use patterns in Table 5b. This technique is relatively common in agricultural economics, where land fallowing is included in economic analysis. In more urbanized settings, land trusts and open space districts may have current data on the costs of development rights purchased through conservation easements. Also, local agency economic development departments and chambers of commerce may also have data on the contributions of various types of development to the local economy.

Table 5c Water Sales Revenue: In this analysis, water sales revenue should be accounted for because the pricing system for recycled water is often different from the pricing for potable water. Some agencies do have a policy of paying users to accept recycled water (this is not recommended when high quality tertiary water is the recycled water product). However, if this is the case, the entry to Table 5c would be a negative number.

Table 5d Total Water Supply Benefits: This table uses information generated in Tables 5a through 5c to calculate the net present benefits of the project.

Table 6 Benefit/Cost Ratio: This table compares Benefits to Costs. In theory, a Benefit/Cost Ratio of greater than 1 indicates that the recycled water source is the preferable source of water. However, remembering that the costs curves utilize order-of-magnitude estimating techniques, an agency may wish to consider a “band of accuracy” in the B/C ratios where ratios between 0.7 and 1.5 are considered to represent water sources with comparable order of magnitude costs. Again, other non-economic factors could be used to make a decision. These factors might include neighborhood sensitivity, a policy preference in favor of recycling or a policy preference to preserve the highest qualities of water for the highest use (which may include environmental water).

Table 1
Project Performance

	(A)	Average Annual Increase in Delivery (AF) 1	

1 Row (A) is the demand that could be met by recycled water

Table 2
Capital Costs

	A	B	C	D	E	F
				Contingency Costs		
	Capital Cost Category	Cost	Replacement Costs (Discounted)1	Percent	Dollars ((B+C)xD)	Subtotal (B+C+E)
1	Land Purchase/Easement				$0	$0
2	Planning/Design/Engineering			inc	$0	$0
3	Materials Costs			inc	$0	$0
4	Labor Costs			inc	$0	$0
5	Equipment Purchases/Rentals			inc	$0	$0
6	Environmental Mitigation/Enhancement			inc	$0	$0
7	Construction Administration/Overhead			inc	$0	$0
8	Subtotal Project Costs					$0
9	Agency Overhead Costs				$0	$0
10	Project Legal/License Fees				$0	$0
11	Other				$0	$0
12	Grand Total (8 thru 11)	$0				$0

1 Divide any future replacement cost by 1.06Y where Y is the number of years into the future that the replacement cost will occur.

Table 3
Annual Operations and Maintenance Costs

A	B	C	D	E	F
Annual Administration	Annual Operations	Annual Maintenance	Annual Other	Total Annual O & M Costs (A+…+F)	Total Discounted O&M Costs (E x 15.7)
				$0	$0

2 Total value of O&M costs over a 50-year period with discount rate of six percent

Table 4
Total Cost Summary

A	B	C
Capital and Replacement Costs1	Discounted O&M Costs2	Total Discounted Project Costs (A+B)
$0	$0	$0

1From Table 2, column (F) row (12)
2From Table 3, column (F)

Table G-5
Project Water Supply Benefits (Parts a and b)

Table 5a
Avoided Costs of Current Supply Sources

	B	C	D
Supply Sources1	Cost of Water ($/AF)	Annual Displaced Supply (AF)	Annual Avoided Costs ($) (B X C)
Totals		0	$0

1 Enter in order from most to least expensive source per unit of water.

Table 5b
Avoided Costs of Future Supply Sources

A	B	C	D	E	F	G	H	I	J
Future Supply Sources2	Total Capital Costs ($)	Capital Recovery Factor3	Annual Capital Costs ($), BxC	Annual O&M Costs ($)	Total Annual Costs ($), D+E	Annual Supply (AF)	Annual Costs ($/AF), F/G	Annual Displaced Supply (AF)	Annual Avoided Costs ($), HxI
							#DIV/0!	0	#DIV/0!
		0.0634	$0				#DIV/0!	0	#DIV/0!
							#DIV/0!	0	#DIV/0!
		0.0634	$0				#DIV/0!	0	#DIV/0!
		0.0634	$0				#DIV/0!	0	#DIV/0!
									$0
Total									#DIV/0!

2 Enter in order from most to least expensive source per unit of water.

3Six percent discount rate; 50 years.

Table G-5
Project Water Supply Benefits (Continued) (Parts c and d)

Table 5c
Water Sales Revenue (Vendibility)

A	B	C	D	E	F	G	H
Parties Purchasing Project Supplies	Annual Amount of Water to be Sold (AF)	Projected Selling Price ($/AF)	Gross Annual Expected Sales Revenue ($) (BxC)	Other Costs ($)	Net Annual Expected Sales Revenue ($) (D-E)	Optional Fee ($) 1	Annual Expected Total Revenue ($) (F+G)
			0		$0		$0
			0		$0		$0
			0		$0		$0
			0		$0		$0
			0		$0		$0
Total	0						$0

1 Option fees are sometimes paid by a contracting agency to a selling agency to maintain the right of the contracting agency to buy water whenever needed. Although the water may not be purchased every year, the fee is usually paid every year.

Table 5d
Total Water Supply Benefits

A	Annual Avoided Costs of Current Supply Sources ($). (from 5a, column D total)	$0
B	Annual Avoided Costs of Future Supply Sources ($). (from 5b, column J total)	#DIV/0!
C	Annual Expected Water Sales Revenue ($). (from 5C, column H total)	$0
D	Annual costs of water shortages ($)2.	
E	Total Annual Water Supply Benefit ($). (A+B+C+D)	#DIV/0!
F	Total Discounted Water Supply Benefits ($). (Ex15.7)3	#DIV/0!

2 Annual costs of shortages as an alternative to the project must be fully documented.

3 Discounted water supply benefits for 50-year period with discounted rate of 6%.

Table 6
Benefit/Cost Ratio

A	Total Discounted Water Supply Benefits1 ($)	#DIV/0!
B	Total Discounted Project Costs 2 ($)	$0
C	Benefit/Cost Ratio (A/B)	#DIV/0!

1 From Table 5d, Row F.

2 From Table 4, Column C.

Table 7
Unit Cost of Water Produced

A	Total Discounted Project Cost1 ($)	$0
B	Annualized Project Costs ($), row A/15.7	$0
C	Average Annual Project Yield2 (AF)	0
D	Cost per Acre Foot ($/AF), row B/row C	#DIV/0!

1 From Table 4, Column C.

2 From Table 1.

Appendix C
Alternative Technologies

GREAT CIRCLE WATER

Product Overview

Patented Point of Need Water Recycling

Contact: Ken Wooller, CEO
3 Reserva Lane
Tiburon CA 94920
Phone: (415) 435-3832
E-mail: kwooller@greatcirclewater.com

About the Company

Great Circle Water, Inc. (GCW) is an early-stage company that has developed patented equipment and process technologies for production of distributed recycled water for non-potable uses. GCW equipment will extract source water from nearby sewers and purify this water for local use. Initial markets addressed are irrigation for golf courses, office parks, athletic fields, agriculture and freeway landscaping. The products are currently being developed and tested on site at the wastewater treatment plant of the Dublin San Ramon Services District in Pleasanton, CA. GCW expects to sell products with Title 22 certification by mid 2004.

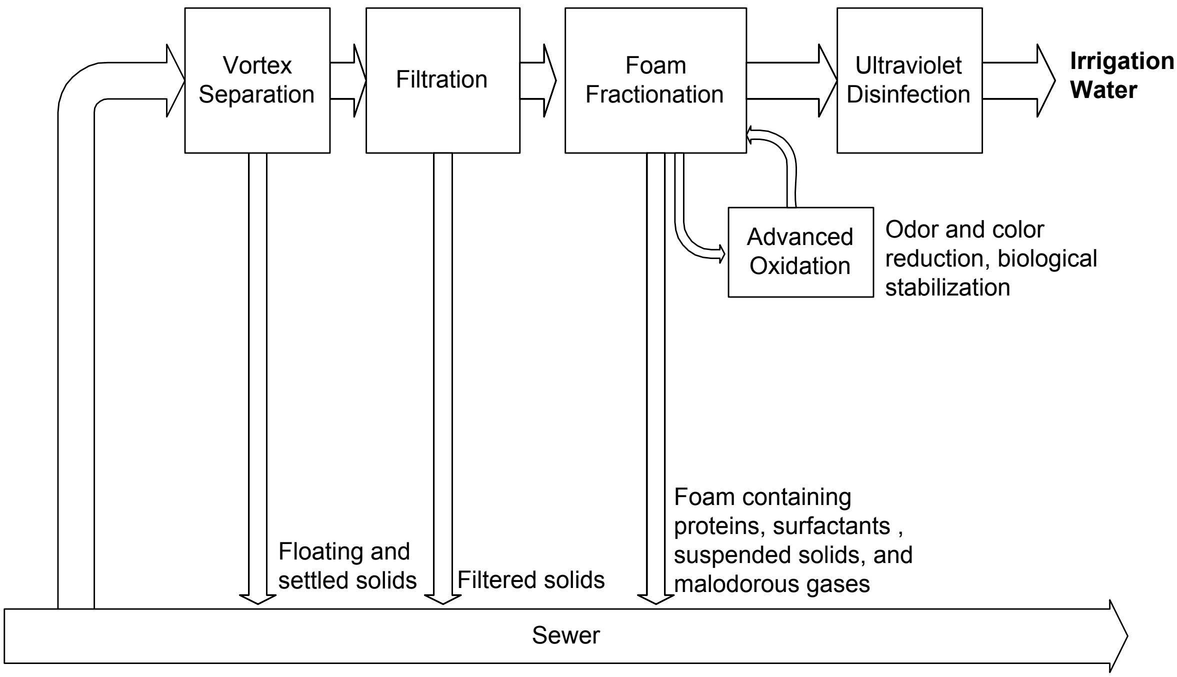
Technology / Product

GCW systems will produce water that is consistently low in odor and suspended solids, thoroughly disinfected, but with nutrient levels suitable for irrigation uses. Product installations will be odorless, quiet, automatic, and very compact, allowing them to be unobtrusively sited near residences and in populated areas. The processes used are all modular and easily scaled, allowing a wide range of capacities to be served, from less than 50,000 to over 500,000 gallons per day. The physical processes used are highly consistent and reliable, lending themselves to completely automatic, fail-safe operation, with remote monitoring. By virtue of their non-biological approach and associated short retention times, the installations can be turned on and off as needed, providing the amount of water required, when it is required. The only regular supply consumed by the process is electricity

Figure 1 presents a schematic diagram of the initial GCW product, and a list of associated benefits. The stages of treatment combine, in a unique and synergistic way, known processes and products that have proven themselves in other applications. Vortex separation in combination with fine filtration and foam fractionation removes settleable floatable and suspended solids. These treatments are followed by a combination of advanced oxidation and ultraviolet radiation which remove odor, biologically stabilize the water, and thoroughly disinfect it. Ultraviolet radiation is well recognized as being extremely effective in inactivating both bacteria and viruses, more so than commonly-used chlorine disinfectants, which also present handling hazards and create carcinogenic byproducts.

The process recovers 85% of the influent as irrigation water, returning the remainder with solids residuals to the sewer. That portion returned to the sewer is finely ground by the GCW equipment into a form that is more easily transported by the sewer and more readily treated at the central plant. COD/BOD returned to vegetation and soils as nutrients is diverted from the central treatment plant, thereby effectively reducing energy and chemical consumption at the plant, while also reducing sludge generation, and pollutant discharges into surface and ground waters.

The process encompasses much less volume and uses a much smaller footprint than conventional biological processes offering the same treatment capacity. Operation can be initiated and terminated quickly and frequently. The process is also very simple to regulate and monitor, unlike biological processes.



- Low cost
- Small footprint
- Low energy use
- Rapid startup/shutdown
- No process chemicals or supplies
- Reliable, consistent performance
- Good process and effluent esthetics
- Water meets Title 22 disinfection requirements
- Automatic, fail-safe operation; remote monitoring
- Off-the-shelf components and proven processes

Figure 1 GCW Process for Irrigation Use

Product Benefits

Benefits of the product are detailed below:

Low cost

The installed user cost of a 100K gallon per day system, excluding the associated shelter and the sewer system interconnection (which are both very site-specific), is projected at under $300,000. Operating costs are projected to be less than $1.50 per 1000 gallons, including all charges for: energy, operational and service labor, supplies, replacement parts , and off-site monitoring. These capital and operating costs taken together yield a life cycle cost for delivered water that is significantly lower than that of prevailing water recycling approaches.

Small footprint

A 50k gallon per day installation has a footprint of less than 170 sq. ft. Such an installation can fit into an unobtrusive utility building the size of a two-car garage. Larger installations will be even more space efficient. This compact installation is the result of the low retention time of the process, which is about 30 minutes, and which compares with hydraulic retention times of 8 to 16 hours for conventional biological plants.

Low energy use

Electrical energy consumption for delivered water from the GCW process is significantly lower than that for prevailing irrigation water sources, as can be seen below:

Source of Water	Energy Use (kWh/1000 gal
Great Circle Water	4.5 -6.7
Central treatment with Pipeline Distribution	6.3–7.1
Central Treatment with Groundwater Injection	6.5-8.0
Desalination of Sea Water	9.6-17.3
California State Water Project to Los Angeles	9.2

Rapid startup/shutdown

The system starts up in about 45 minutes, and shuts down in less than 15. These intervals are dramatically lower than those for biological systems, which require weeks to reach stability, and must be operated continuously to maintain proper performance. The ability to turn on and off quickly allows the GCW system to provide just the right amount of irrigation water when it is needed. The control of irrigation volumes assures balance with the ecosystem, and avoids the potential for runoff or groundwater pollution.

No process chemicals or supplies

Aside from cleaning chemicals that are used infrequently, the process requires only electricity. This minimizes the logistical needs, costs and hazards of operation.

Reliable, consistent performance

The physical process stages used are robust and inherently stable. Process throughput is essentially constant. Solids residuals are isolated and returned to the sewer.

Good process and effluent esthetics

The low retention time of the process, the injection of abundant amounts of oxygen, and the use of enclosed tanks all assure no generation of odors. Irrigation water produced is consistently free of visible suspended solids and has minimal odor.

Water meets Title 22 disinfection requirements

Preliminary tests show that the process produces an effluent containing less than 2.2e. coli MPN per 100 ml, thereby meeting the State of California Title 22 disinfection requirements for the most restrictive irrigation uses. With ultraviolet disinfection such as is used by the GCW process, such a low coliform count also assures substantial deactivation/kill of all waterborne viruses.

Automatic, fail-safe operation; remote monitoring

The process is inherently simple and self-regulating; controls are used only for input flow balancing, system monitoring, alarming and failure diagnosis. A variety of sensors – including pressure, flow, level, voltage, current, suspended solids, and temperature – allow the process to be thoroughly monitored and supervised by ssoftware-based industrial controls. Fail-safety is assured by the basic processes employed, combined with failure detection software, and a quick shutdown strategy, wherein throughput is terminated and all tanks are drained back to the sewer. Treatment sites will be monitored remotely via internet-based links using PCs with password-enabled web access.

Off-the-shelf components and proven processes

All stages of treatment use proven processes and designs, and involve primarily off-the-shelf components.

Comparative Performance

There are no known suppliers of packaged distributed "Point Of Need" water recycling systems. The biological processes likely to be used by potential competitors are expensive, bulky, maintenance-intensive, odor-prone, and unreliable. Valid comparisons are therefore with current alternative sources of new water for irrigation use: upgraded central treatment plants with newly constructed recycled water distribution pipelines or groundwater injection facilities, and new seawater desalination systems. Table 1 compares GCW Products with both existing and prospective competitors, using various attributes as bases for comparison.

● ◍ ○
Excellent ◄—► Poor

		Installed Capital Cost	Operating Cost	Siting Flexibility	Space Requirements	Implementation Time	Political Acceptibility	Modular Expandability	Oversight Requirements	Consumption of Supplies	Process Reliability	Title 22 Compliance	Energy Consumption	Esthetic Desirability
	Great Circle Water	●	●	●	●	●	●	●	●	●	●	●	●	●
Existing Competitors	Central treatment - distribution	○	●	○	●	○	○	○	●	○	○	●	◍	○
Existing Competitors	Central treatment - groundwater inj.	◍	○	○	●	○	○	○	●	○	○	●	○	○
Existing Competitors	Desalination of sea water	◍	◍	◍	●	○	◍	●	●	●	●	●	○	●
Potential Competitors	Membrane Bioreactor System	◍	○	◍	◍	◍	●	◍	◍	◍	◍	●	○	◍
Potential Competitors	Fixed Film Biofilter System	◍	◍	○	○	◍	●	○	◍	◍	○	◍	◍	◍

Table 1 Comparative Attributes of Irrigation Water Sources

Compared with the current large-scale centralized approaches, GCW installations avoid the huge capital costs, long timelines, and negative environmental impacts associated with major pipeline construction projects. In terms of operating costs, the GCW process uses significantly less energy than systems using membranes for treatment of wastewater and systems using either membranes or vapor recovery for desalination of seawater . As a satellite system, it eliminates needless energy costs for pumping of water to and from distant treatment plants.

Product Development, Demonstration and Testing

GCW is developing and testing its product with the benefit of a testing/demonstration site at the Dublin San Ramon Services District wastewater treatment plant in Pleasanton, California. The District has been very supportive in this endeavor, being a leading agency in pursuing and promoting water recycling. The test site is an excellent location for such development work, containing a shelter-enclosed prototype, and a trailer lab with test equipment for measurement of most critical water quality parameters. The prototype has a treatment capacity of 50,000 gallons per day, which is the building block module for installations of all sizes. The site continues to be used for testing and evaluation of design refinements.

The commercial GCW product is now being engineered under contract by Pipeline Systems Inc. (www.pipesys.com). PSI is a leading full service control system integrator with extensive experience and strong capabilities in process and factory automation. Their previous projects have included aquariums, and municipal water and wastewater systems.

Concurrent with commercial product development, GCW will subject an upgraded version of its prototype to four months of formal testing at the DSRSD test site for the purpose of obtaining Title 22 certification. Title 22 is the State of California code governing use of recycled water for non-potable applications, and has become a defacto international standard. The certification process requires that a municipal agency make a formal request for such certification to the State of California Department of Health Services, which administers the Code. The Dublin San Ramon Services District has agreed to serve as this municipal agency sponsor. The formal tests and submittals are being planned and will be implemented with the assistance of an independent consulting firm, Carollo Engineers (www.carollo.com), Carollo Engineers is a respected, highly qualified environmental engineering firm specializing in the planning, design, and construction management of water and wastewater facilities.

Great Circle Water, Inc expects to install a certified beta version of its water recycling system product by the second quarter of 2004. GCW is currently investigating preferred sites for this purpose in the San Francisco Bay Area; it also has a prospective municipal customer in Colorado, which seeks to install a beta site in its Colorado jurisdiction.

AQUATIC ROOT ZONE-INTEGRATED FIXED-FILM ACTIVATED SLUDGE LIVING MACHINE™ SYSTEMS

Aquatic Root Zone – Integrated Fixed-Film Activated Sludge (ARZ-IFAS) Living Machine™ systems are biological nutrient removal (BNR) treatment systems that use plants as a key treatment component. This Living Machine™ technology has been extensively evaluated by the US EPA[1,2].

A distinguishing feature of the Living Machine™ systems is the designed use of plants and the associated root zone of the grazing organisms. Plant roots grow directly into aerated wastewater from racks fixed at the water surface of the treatment basin. Biofilms growing on plant roots and biosolids retained on plant roots are key treatment mechanisms. A diverse and abundant community of invertebrate organisms thrives in the plant roots by grazing on biofilms and retained biosolids.

Living Machine™ systems are both environmentally and ecologically engineered. Ecological engineering is manifested in the careful selection of plant species known to thrive and produce long roots in wastewater. The communities of invertebrate grazing organisms, scientifically termed *detritivores*, are also deliberately introduced into Living Machine ™ systems. The detritivore ecology in the plant root zone is a fundamental feature of traditional Living Machine™ systems and the family of technologies developed by Living Machines, Inc. The beauty of the plants emerging from the treatment basin is, in a sense, a bonus to human aesthetics for plant roots and associated ecology that do hard treatment work. Only negligible treatment appears to be done by uptake of nutrients into plants.

Most components of Living Machines™ systems are familiar to wastewater treatment professionals. These treatment components include headworks, anaerobic/anoxic reactors, pumps, blowers, air diffusers, programmable logic controllers, activated sludge, clarifiers, post-clarifier filtration, and disinfection systems.

ARZ-IFAS Living Machine™ Treatment Process

ARZ-IFAS Living Machine™ treatment process is comprised of a series of separate steps. Not all of the individual treatment steps listed below will be needed for a given application. All applications will employ aerated treatment basins covered with plants.

---

[1] **US EPA**. 2001. The "*Living Machine*" Wastewater Treatment Technology: An Evaluation of Performance and System Cost. Municipal Technology Branch Office Of Water U.S. Environmental Protection Agency Washington, DC. In press.

[2] **Austin, David. Meyer, Jerry. Fluck, Steve. von Rohr, James R**. 2000. *Final Report on the South Burlington, Vermont Advanced Ecologically Engineered System (AEES) for Wastewater Treatment*. Unpublished report to US EPA.

Headworks

Wastewater arrives at the Living Machine™ treatment system headworks. "Headworks" is a general term for the first part of a wastewater treatment facility to receive wastewater. Types of headworks vary with the size of the treatment system and site considerations. The purpose of headworks is remove large debris and grit that are not treatable in the wastewater treatment system. Headworks may also contain advanced screening of wastewater that is more of a pretreatment step than a mere rough debris and grit removal.

Headworks can produce foul odors emanating from untreated wastewater. Control of these odors is essential if a wastewater treatment plant is located next to residences or business. Fortunately, odor control technology is highly effective with a careful selection of odor scrubbing technology which is site and scale dependent.

After the headworks, wastewater proceeds to initial treatment steps. These steps vary with the size of the treatment system and type of wastewater. In some instances, influent may arrive essentially debris-free, thereby simplifying or eliminating the need for traditional headworks.

Anaerobic Reactor

For debris-free, domestic effluent under flows of approximately 20,000 gpd, primary tanks can be used as passive anaerobic reactors that are a cost effective primary treatment system (in order to avoid confusion between a septic tank and a septic system, LMI prefers to use the term primary tank). Typically, headworks are not needed for these applications. Gases from anaerobic reactors are vented through odor control systems that scrub out hydrogen sulfide gas and offensive trace organics. These passive anaerobic pretreatment systems remove grit, floatable waste, and most grease and oil, and some BOD.

Anoxic Reactor

The purpose of the anoxic reactor is to denitrify effluent. Wastewater is extracted prior to the inlet of the clarifier and is pumped to the anoxic reactor. Nitrate in the recycled wastewater combines with raw or pretreated wastewater and then is converted to atmospheric nitrogen by bacterial metabolism. Reactor biomass is comprised of recycled activated sludge (RAS) from the clarifier and biofilm attached to a buoyant carrier media.

The anoxic reactor is mixed and intermittently aerated to prevent anaerobic conditions while promoting the growth of floc-forming and denitrifying microorganisms. These microorganisms will remove a significant portion of the incoming BOD and convert nitrate to nitrogen gas (denitrification). The anoxic reactor environment is between anaerobic and fully aerobic in terms of the oxygen content in the wastewater. There is effectively no free oxygen (O_2) in the wastewater; oxygen is present in bound forms of nitrates, sulfates and other compounds. The anoxic state is maintained by controlled aeration. An oxidation-reduction potential (ORP) probe in the reactor controls aeration to maintain ORP conditions inside the reactor within the anoxic design range. A constant recycle of process water from the last aerated reactor to the anoxic reactor returns nitrate for conversion to nitrogen gas.

Covered Aerobic Reactor

The Covered Aerobic Reactor (CAR) follows the anoxic reactor and is the first step in the fully aerobic portion of the Living Machine™ treatment process. The purpose of this reactor is to remove a large fraction of the BOD in the effluent from the anoxic reactor, and to strip odoriferous gases from the wastewater. Some conversion of organic and ammonia nitrogen to nitrate (nitrification) occurs in this reactor. The Covered Aerobic reactor is aerated with fine bubble diffuser(s) to provide oxygen required for treatment and mix the contents. Reactor biomass is comprised of RAS and biofilm attached to a buoyant carrier media.

Odor Control

To control odors at both the anoxic reactor and the covered aerobic reactors, planted biofilters consisting of approximately 2 feet of compost material and inert media, are situated directly over each reactor. The biofilters are planted with vegetation primarily to ensure that the biofilter is kept at an appropriate moisture content. Alternatively, in larger reactors, a floating cover can collect gases and vent them to an odor scrubbing system.

Hydroponic Reactors

The Hydroponic Reactors follow the Covered Aerobic reactor. These reactors reduce the BOD to less than 10 mg/L which allows for almost complete nitrification of ammonia-nitrogen to concentrations of less than 1 mg/L. The Hydroponic Reactors are aerated with fine bubble diffusers, which provide the oxygen required for microbial metabolism and keep the tank contents mixed. Reactor biomass is comprised of RAS and biofilm attached to plant roots.

The surface of the Hydroponic Reactors is covered with vegetation supported on racks. The roots of the vegetation provide surfaces for the growth of attached microbial populations that assist in the wastewater treatment. The vegetation serves as habitat for invertebrate detritivores that consume microbial biomass. The grazing reduces the sludge volume generated and prevents excessive biofilm growth. Also, the vegetation and racks reduce the surface turbulence in the reactor, which reduces the formation of aerosols and volatilization of odor compounds.

Clarifier

The Clarifier follows the Hydroponic Reactors and is the next treatment step in the Living Machine™ system. The purpose of the Clarifier is to separate the microbial solids from the treated wastewater stream using gravity settling. Some of the settled microbial solids (biosolids) are returned to the anoxic reactor to provide active microbial populations for the treatment process. Settled biosolids that are not recycled are removed from the clarifier and handled as described below.

Post-Clarifier Filtration

Effluent from the clarifier is usually very clear. However, the settling characteristics of biosolids may undergo transient changes that degrade clarifier performance. Disinfection performance can be degraded by these undesirable changes in clarifier performance. Standard engineering practice to ensure effective disinfection and high-quality effluent is to place some form of filtration system between the clarifier and the disinfection system. For high quality reuse applications, filtration is typically mandated by prescriptive regulatory standards.

Post-Clarifier Filtration – Polishing Wetland

For sites that have sufficient space, the post-clarifier filtration step can be effectively accomplished with a planted vertical flow polishing filter or wetland. Effluent from the clarifier is dosed on the wetland surface to flow down through plant roots and media to a bottom drain system. Biosolids not captured in the clarifier are strained out of water by plant roots and media and consumed by detritivores in the wetland. Periodic draining of the wetland prevents long-term formation of anaerobic conditions. Effluent from the bottom drain is very clear and suitable for disinfection. These polishing wetlands are compact in comparison to standard treatment wetlands and will operate outdoors even in severe winters.

Other Post-Clarifier Filtration Options

For sites that have limited space, a textile filtration system will produce effluent of superb clarity with simple operation. The Fuzzy Filter ™ (Schreiber Corporation) and the Aquadisc Filter ™ (Aqua-Aerobics Systems, Inc.) are two examples of modern textile filter technology that can be used in Living Machine™ Treatment systems. Conventional filtration technologies, such as rapid sand filtration, may be satisfactory.

Disinfection

Effluent from the clarifier flows to a disinfection system. Living Machines, Inc. strongly advises against the use of free-chlorine or chloramine based disinfection because they create toxic byproducts.

Ultraviolet (UV) disinfection relies on ultraviolet radiation to render bacteria and viruses non-infective by disrupting their DNA and/or RNA. The UV disinfection leaves no residual disinfectant and requires effluent with low turbidity and little color to be effective.

Living Machines, Inc., through its sister company, Water Technologies, Ltd., also offers the Curoxin™ chlorine dioxide disinfection system. Long recognized in the drinking water industry as a powerful disinfectant that produces no harmful byproducts in disinfected water, chlorine dioxide is becoming an increasingly attractive disinfection option for wastewater. The Curoxin™ system used to manufacture the chlorine dioxide on site is proprietary to Iasis, Ltd., the parent company of Living Machines, Inc.

Filtrate Disposal

Automated filter cleaning processes produce a filtrate side stream that requires further processing. Filtrate can be recycled to the front of the system for continued digestion or composted in an on-site reed bed or disposed of off-site. The volume and frequency of filtrate disposal and method of processing depends on the type of filtration employed and quantity of feed water.

Biosolids Disposal

The optimal means for the disposal of waste biosolids depends almost entirely on site-specific considerations such as, Living Machine™ system size, and local regulations. For small systems under 20,000 gpd, hauling waste biosolids off site by a sludge or septic hauler may be cost effective. Larger systems will typically require more sophisticated methods. In some instances, aerobic stabilization followed by biosolids composting in reed beds is a highly desirable and cost effective solution. Because of the variables involved, optimal biosolids disposal options determined on a case-by-case basis.

Plant Composting

Plants grow at a high rate with ample water, nutrients, and sun. Periodic mowing of plants is necessary to reduce plant biomass and to maintain the overall health of the plant community. Manual mowing/cutting and composting of plant biomass is cost effective for systems of approximately 100,000 gpd or less. The design details for larger treatment systems typically include mechanically assisted mowing and composting.

Applications

Living Machines, Inc. has designed Living Machine™ treatment systems for domestic and institutional sewage and industrial food waste. Our market focus is domestic sewage, however high-strength food processing wastewater projects can be ideal Living Machine™ applications. Domestic wastewater projects have included resorts, boarding schools, visitor centers, museums, botanical gardens, and municipal applications. All of these applications have required close proximity of wastewater treatment to areas receiving heavy foot traffic. Aesthetics and odor control have been key design elements of all these applications in addition to high effluent standards.

Treatment Levels

Treatment levels are usually dictated by discharge requirements. Treatment to higher levels may be desirable in many cases to expand re-use options, give greater safety margins, and reduce maintenance. Maximum Living Machine™ system treatment levels for domestic wastewater are summarized in Table 2-1. This maximum level of treatment is suitable for advanced reuse applications such as spray irrigation, where allowed by regulatioins, and discharge to sensitive surface waters. Maximum treatment effluent values are suitable for reverse osmosis feed water.

Table 2-1. Maximum Treatment Levels – Root Zone-IFAS Living Machine™ Systems

Parameter	Best attainable effluent standard	Note
BOD_5	≤5 mg/L	
Total nitrogen	≤10 mg/L	
Ammonia	≤1 mg/L	
Phosphorous	40% removal	Increased phosphorous removal will require additional chemical/physical unit processes.
TSS	≤5 mg/L	Typically requires post clarifier filtration
Turbidity	2 ntu	Requires post clarifier filtration
Fecal coliforms	< 2.2 cfu/100ml	Requires post clarifier filtration and disinfection.

A lower level of treatment is commonly sufficient to meet discharge requirements and is summarized in Table 2-2.

Table 2-2. Common treatment levels – Root Zone-IFAS Living Machine™ Systems

Parameter	Effluent standard	Note
BOD_5	10 mg/L	
Total nitrogen	15 mg/L	
Ammonia	3 mg/L	
Phosphorous	40% removal	Increased phosphorous removal will require additional chemical/physical unit processes.
TSS	10 mg/L	With post-clarifier wetland.
Turbidity	15 ntu	With post-clarifier wetland.
Fecal coliforms	100 cfu/100ml	Disinfection.

IMPORTANCE OF PLANTS IN LIVING MACHINE™ SYSTEMS

The impact of plants on wastewater treatment is directly proportional to their root penetration and density. Roots must deeply penetrate wastewater to affect treatment. Long, dense masses of roots significantly affect treatment. Short roots do not. Many plants will thrive with roots in wastewater, but only a small subset of those plants will produce the roots that make them useful for treatment. Careful, exclusive selection of plants known to produce long, dense root masses is a key element of Living Machines, Inc. designs.

Plants in Hydroponic Treatment

In hydroponic reactor systems, such as ARZ-IFAS Living Machines™ systems, plants installed on racks at the water surface send roots into wastewater. After years of research on hundreds of plant species, Living Machines, Inc. has determined that a reliable depth of penetration for dense root mats is approximately two feet. Greater depths of penetration do occur, but two feet is a safe design standard.

All hydroponic reactors systems designed by Living Machines, Inc. are restricted to a select list of plants. Criteria for selection of plants go beyond depth of root penetration. Hardiness in the wastewater environment, resistance to pests, and suitability for the site environment are other key selection concerns. Investigation of other species continues.

Depth of root penetration into wastewater must be considered in proportion to the depth of the treatment basin. The consensus among experts[3] who have studied water hyacinth wastewater treatment systems is that roots must densely penetrate approximately 20-30% of the wastewater column to significantly affect treatment. Living Machines, Inc. concurs with the experts. The same criterion applies to all hydroponic treatment systems. With a two foot-deep root mass 30% penetration therefore requires that a hydroponic treatment basin be no more than six feet deep.

Wastewater must circulate or pass through the root mass for plants to contribute to treatment. Aeration or hydraulic mixing creates the circulation patterns necessary to pass wastewater though plant roots. Flow may also be directed through the root mass via a surface collection system in each treatment basin.

The role of plant roots in hydroponic treatment appears to have three main elements: retention of suspended biosolids, substrate for biofilm growth, and creation of a habitat for large populations of invertebrate organisms that graze on bacterial biomass.

Retention of biosolids is an important treatment mechanism in ARZ-IFAS[4] Living Machine™ systems. The effect of biosolids retention is to stabilize treatment by retarding biosolids washout and to reduce yield. Reduction of yield is a consequence of grazing of biosolids by invertebrates and endogenous respiration of retained bacteria biomass. Retention of biofilms on plant roots sloughed from carrier media in upstream reactors is a treatment mechanism currently under evaluation.

Biofilms grow on submerged plant roots. These biofilms do play a key treatment role in water

---

[3] Oral communication from Robert Bastian, US EPA Office of Water Management; George Tchobanoglous, Professor Emeritus, Department of Civil and Environmental Engineering, University of California-Davis; Sherwood Reed, US Army Corps of Engineers (retired).

[4] **Austin, David**. 2001. Parallel Performance Comparison Between Aquatic Root Zone - and Textile Medium - Integrated Fixed-film Activated Sludge (IFAS) Wastewater Treatment Systems. Proceedings Water Environment Federation Technical Conference 2001, Atlanta, Georgia.

hyacinth treatment systems[5]. Undoubtedly, biofilms growing on plant roots play a significant treatment role in Living Machine™ systems.
The root zone in water hyacinth treatment systems is known to host a diverse microbial community[6]. The same is true for Living Machine™ systems. Grazing of bacterial biomass is an important mechanism to achieve low yield (mass effluent VSS / mass influent BOD_5) in water hyacinth treatment systems[7] that can produce tertiary or near tertiary quality VSS effluent concentrations[8]. Selection of Living Machine™ hydroponic system plants with large, dense root masses and placing them in shallow reactors both maximizes habitat for grazing organisms and their access to bacteria biomass produced in wastewater.

Plants in Wetland Treatment

Decades of experience with wastewater treatment wetlands have provided a long list of plants suitable for this application. Because treatment wetlands are usually outdoors, use of native plant species is often desirable.

The role of plants in wastewater treatment wetlands is controversial. Results from studies comparing vegetated and unvegetated horizontal, subsurface flow gravel beds indicate that plants do not significantly impact treatment[9,10]even though there is strong evidence that the presence of roots significantly affects the composition of microbial populations[11]. In horizontal subsurface flow wetlands, roots tend to grow little below the permanently wetted media surface, and tend to create a dead zone through which little wastewater flows[12]. Obviously, roots cannot affect treatment if not effectively in contact with wastewater.

The design of horizontal subsurface flow wetlands is largely incompatible with deep penetration of roots into the wastewater treatment column. Plants need only send down roots a short distance to obtain abundant water and nutrients. As in hydroponic reactors, few plants will send down long roots under such conditions. Part of the lack of root penetration may also be attributed to dense gravel media that is not easily penetrated by roots adapted to growing in

[5] **Tchobanoglous, George. Maiski, Frank. Thompson, Ken. Chadwick**, **Tomas.** 1989. *Evolution and Performance of City of San Diego Pilot-scale Aquatic Wastewater Treatment System Using Water Hyacinths*. Research Journal Water Pollution Control Federation, November/December 1989.
[6] **Reed, Sherwood. Crites, Ron. Middlebrooks, E**. 1995. *Natural Systems for Waste Management and Treatment*, 2nd Ed. Chapt. 5. McGraw-Hill.
[7] **Crites, Ron. Tchobanoglous, George**. 1998. *Small and Decentralized Wastewater Treatment Systems*. McGraw Hill.
[8] **Western Consortium for Public Health (WCPH). EOA, Inc.** 1996. *Total Resource Recovery Project, Final Report.* City of San Diego Water Utilities Department.
[9] **US EPA**. September 2000. *Constructed Wetland Treatment of Municipal Wastewaters.* EPA/625/R-99/010.
[10] **Watson, J. Danzig, A**. 1993. Pilot-Scale Nitrification Studies Using Vertical-Flow and Shallow Horizontal-Flow Constructed Wetland Cells, in *Constructed Wetland for Water Quality Improvement*. G. Morshiri, Ed. Pp. 301-313. Lewis Publishers.
[11] **Hatano, K. Trettin, C. House, H. Wollum, G**. 1993. Microbial Populations and Decomposition in Three Subsurface Flow Constructed Wetlands, in *Constructed Wetland for Water Quality Improvement*, G. Morshiri, Ed. Pp. 541-548. Lewis Publishers.
[12] **US EPA**. September 2000. *Constructed Wetland Treatment of Municipal Wastewaters.* EPA/625/R-99/010.

muck.

Living Machines Inc.'s vertical flow wetland designs maximize the contribution of plant roots to treatment. Dosing wastewater on top of the root mat forces wastewater to pass through the root mass. Formation of a thick mat of interwoven roots is typical of wetland perennial species. Additionally, the media specified is a combination lightweight ceramic aggregate and plastic that is easily penetrated by plant roots, allowing for much deeper root penetration.

Plants in natural wetlands sustain communities of grazing organisms that consume bacterial and algal biomass. The same is true for surface flow wetlands. Horizontal subsurface flow wetlands, however, provide essentially no habitat for invertebrate grazer communities. Either the plant thatch is too dry, or the subsurface wetted zone does not have enough oxygen to support any higher aquatic invertebrates, such as rotifers, amphipods, copepods, and beneficial insect larvae.

Most obligate wetland plants do pump oxygen to their roots. However, mass flux of oxygen to the roots is too small to support more than plant physiology and a thin film of microaerophilic bacteria. Microaerophilic bacteria oxidize anaerobic compounds, such as H_2S, that are toxic to plants. Pumping of air to plant roots is an energy cost to plants. In highly reducing wetland soils, plant growth is stunted by the need for plants to expend excess energy to oxidize plant roots. There is not sufficient oxygen to support higher organisms that are associated with roots in soils with positive dissolved oxygen concentrations.

The vertical flow wetland designs by Living Machines, Inc. support a community of higher aquatic invertebrates. In Tidal Flow Wetland designs the plant thatch and root zone is either moist or flooded. In small re-circulating vertical flow wetlands the plant root zone stays moist and aerobic. Both maintain aerobic zones that will sustain higher aquatic organisms[13]. The action of these grazing organisms keeps the wetland surface from accumulating excessive bacterial biomass that can clog the wetland surface. Without the ecosystem created and sustained by plants a vertically loaded gravel bed will quickly clog at higher application rates.

Distinguishing between the treatment role of plants and media may be difficult for some parameters in vertical flow wetlands. Without doubt, the biofilms on wetland media play a primary role in wastewater treatment. Maximization of plant root growth and communities of associated grazing organisms optimizes the contribution of both media and plants to wastewater treatment.

[13] Insect disease vector larvae, such as mosquitoes or horseflies, however, are excluded from these treatment systems either by lack of habitat or predation.

